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# Agricultural Chemical Use and Ground Water Quality: Where Are the Potential Problem Areas?

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# Agricultural Chemical Use and Ground Water Quality: Where Are the Potential Problem Areas?

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## Purpose and Scope of Study

Perceptions of the magnitude and extent of agriculture's role in ground water contamination will influence the degree to which agriculture is targeted for regulation. Chemicals associated with agriculture have been found in private and public drinking water, and degradation of surface water bodies has been attributed partly to chemical loadings in the ground water that discharges into bays, lakes, and streams. Federal and State policies addressing agricultural contamination of ground water are presently being debated, and in some cases agricultural activities are being restricted in efforts to protect drinking water supplies and the environment.

While the perception of a problem exists, the dangers posed to human health and the environment from the often trace amounts of agrichemicals in the ground water are uncertain. Uncertainty about the extent to which agricultural activities are responsible for ground water contamination also exists.

To address these concerns, the USDA Water Quality Initiative was launched in 1989 and will extend through 1995. The Initiative consists of a variety of programs and projects that 1) helps us understand where and to what extent agriculture is affecting ground water, 2) develops new and modified farming systems that reduce offsite chemical loadings, and 3) helps us learn more about how to implement programs that will induce the appropriate voluntary response by agricultural producers.

This study is part of that effort. ***It is intended to update the public and the policy-making community on the potential for ground water contamination at the national level from the use of agricultural chemicals using the best information available as of mid-1992.*** Two questions provided the primary motivation for the study:

- What areas of the country have the highest priority for study and program implementation?
- What national policy implications emerge from the spatial patterns of the potential for contamination, given information available about farming practices and chemical use in agriculture today?

Ground water vulnerability indexes for pesticides and nitrogen fertilizer were developed for use as decision aids. A national cartographic data base was created in a Geographic Information System (GIS) by overlaying boundaries of counties, hydrologic units, Federal lands, and Major Land Resource Areas (MLRA). The 1982 National Resource Inventory (NRI) data base was embedded in the cartographic data base and used to calculate vulnerability index scores at each NRI sample point.

The scope of the analysis is limited to the assessment of *ground water* vulnerability. Surface water quality problems are also an important part of the overall water quality picture as it relates to agriculture. Areas identified in this study as being low risk areas may still have surface water quality problems associated with agrichemical use.

The study focuses on *shallow* ground water in assessing the potential for contamination to occur. The approach builds on a model that predicts the amount of chemical that leaches past the root zone. In areas where the water table is near the surface, these predictions relate directly to ground water contamination. In others, a time lag is involved. No adjustment in the vulnerability score was made for areas where the water table is deep.

## High Risk Areas

The highest vulnerability index scores for pesticides occur in agricultural areas along the Coastal Plains stretching from Alabama and Georgia north to the Chesapeake Bay area, the Corn Belt States, the Mississippi River Valley, and the irrigated areas in the West. The highest state average scores were for Delaware, Florida, Georgia, Maryland, South Carolina, New Jersey, Indiana, Alabama, and Illinois.

Intrinsic factors are important in the eastern Coastal Plain. The area has high rainfall and a disproportionate amount of acreage with soils that leach pesticides. Even though the land cover in this area is diverse and the proportion that is cropland is low to moderate (cropland acreages for most of these States range from about 15 to 35 percent), the average vulnerability index scores for pesticides remain high.

The Midwest, however, is not generally characterized by intrinsic vulnerability. The majority of the soils in Iowa, Illinois, Indiana, and Ohio have a relatively low potential to leach pesticides, and percolation factors tend to be moderate. These areas score high because of the widespread use of pesticides that leach (such as atrazine).

High vulnerability index scores for nitrogen fertilizer are distributed generally in the same regions as the high vulnerability scores for pesticides. However, vulnerability to nitrogen fertilizer leaching was more predominant in the Corn Belt States—Indiana, Illinois, Iowa, and Ohio have the highest average state vulnerability scores for nitrogen fertilizer.

The agricultural areas of the country that have the highest priority for further study and program implementation are in the Midwest and the Coastal Plain in the South and East.

High vulnerability scores do not necessarily indicate that a ground water problem exists. The vulnerability indexes were derived to classify an area as having the ***potential*** for ground water contamination even if the likelihood was small. The vulnerability indexes serve as a screening criterion consistently applied to all parts of the country to identify areas that are potentially more susceptible to ground water contamination from agrichemical use than other areas.

## Low Risk Areas

Not all cropland is vulnerable to leaching. Regions of the country identified as being in a high risk group also have significant acreages that appear not to be at risk. For all non-Federal rural land, 9.4 percent (128 million acres) is cropland where chemicals are used and has vulnerability index scores for pesticides that are in the low risk range—*about a fourth of all cropland.* States with a disproportionate amount of land in this low risk group are North Dakota, South Dakota, Texas, and Kansas.

## Policy Implications

This study clearly shows that the potential for ground water contamination related to agricultural chemical use is geographically diverse both nationally and regionally. Factors that determine leaching vulnerability differ in every major agricultural region of the country.

*This mix of relative vulnerability presents policy makers with a challenge if they are going to affect changes in problem areas without imposing unnecessary costs on farming in nonproblem areas.*

With the potential for ground water contamination so diverse, it is not likely that simple, across-the-board solutions will work. The geographic diversity of ground water vulnerability suggests that the best approaches will most likely come from State and local governments working together with their national counterparts to derive policies tailored to the unique features of each area.

# Agricultural Chemical Use and Ground Water Quality:
## Where Are the Potential Problem Areas?

## Agriculture and the Ground Water Quality Problem

### Public Concern

Over the last 60 years the agricultural sector has shifted from labor-intensive production methods to more capital-intensive and chemical-intensive production methods. In doing so, it has provided abundant supplies of food and fiber at relatively low cost. Concern about the fate of agrichemicals and their impact on man and the environment emerged in the early 1960s. This concern has intensified within the last 10 years with the discovery of agrichemicals in ground water used for drinking.

A 1985 opinion poll conducted by the Center for Communication Dynamics showed that nationwide nearly 60 percent of respondents (80 percent of the college-educated respondents) agreed with the statement that "farmers use too many pesticides." Only 23 percent of the respondents were willing to accept that drinking water was safe if it met government standards but still contained small amounts of chemicals (Batie, et al. 1986).

### Agrichemicals in Ground Water

EPA began to emphasize ground water monitoring for pesticides in 1979 following discovery of DBCP and aldicarb in ground water in several States. In 1985, 38 States reported that agricultural activity was a known or suspected source of ground water contamination within their borders (Association 1985). Since then several Federal and State agencies have developed programs to sample water resources and test for the presence of agricultural chemicals. Results published to date have shown that chemicals used in agricultural production have been found in ground water, sometimes at levels exceeding EPA's water quality criteria.

- EPA reported in 1988 that 46 pesticides were detected in the ground water of 26 States as a result of normal field operations. Eighteen pesticides were found at levels higher than the Health Advisory Level (HAL), but seven had already been severely restricted or canceled.

- USGS examined the results of 124,000 well samples. They found that 20 percent had nitrate levels higher than natural background levels and 3 percent had levels higher than EPA's Maximum Contaminant Level (MCL). Higher nitrate concentrations were found in agricultural areas than in nonagricultural areas (USDI 1985).

- Preliminary results from USGS's ground water study on the Delmarva Peninsula indicated that pesticides were found in about 20 percent of the shallow wells near the water table. No detections of pesticide concentrations above reporting limits were found in wells that were more than 50 feet deep. Concentrations of nitrates were highest in shallow ground water under farm fields (as opposed to areas associated with alternative land uses) (USGS 1991).

- The Monsanto Agricultural Company conducted the National Alachlor Well Water Survey in 1988-89. They tested for alachlor, atrazine, metolachlor, cyanazine, simazine, and nitrate in 1,430 wells in 26 States. Detectable levels of one or more of the five herbicides were found in 13 percent of the wells, but less than 1 percent exceeded EPA standards for drinking water. About 5 percent of the wells had nitrate levels above the MCL of 10 parts per million (Monsanto 1990).

- On the basis of a national well water survey conducted in 1988-90, EPA estimates that about 10 percent of the Nation's community water system wells and about 4 percent of the Nation's rural domestic wells contain at least one pesticide. No community water system wells and less than 1 percent of the rural domestic wells have pesticide levels above the HAL or MCL. About 1.2 percent of the community water system wells and 2.4 percent of the rural domestic wells are estimated to have nitrate levels above the 10 ppm MCL (USEPA 1990).

These results suggest that agriculture is a source of ground water contamination. Sufficient knowledge about other sources of contamination does not exist, however, to conclude that regulation of farming practices would appreciably improve ground water quality. It has been suggested, for example, that the majority of the pesticides found in ground water may originate from quasi-point sources, such as applicator loading and mixing sites; improper disposal, storage, and handling; and accidental spills. The part of chemical residue in ground water that originates from lawn, garden, golf course, and related uses of similar materials is not well known. We do not know what part of nutrient residue originates from field application of chemical fertilizers versus nitrates from livestock wastes, or from sources unrelated to agricultural activities.

Moreover, exposure to the often trace levels of agrichemicals found in ground water has not been shown to be a widespread threat to human health or to the environment.

Nevertheless, the combination of the potential for health and environmental effects and the irreversible nature of ground water contamination has produced a "safety first" reaction by society and government.

## USDA's Water Quality Initiative

USDA launched a Water Quality Initiative in 1989 that will extend through 1995. The overall goal of the Initiative is to provide farmers, ranchers, and foresters with the knowledge and technical means to respond voluntarily to ground water quality concerns related to agricultural activities. The U.S. Department of Agriculture was directed to achieve this goal in a way that reduces the need for restrictive regulation and in a manner that maintains productivity and profitability. The Initiative involves eight principal USDA agencies, State Agricultural Experiment Stations and Cooperative Extension Services, and related activities of EPA, the Departments of Interior and Commerce, and state universities.

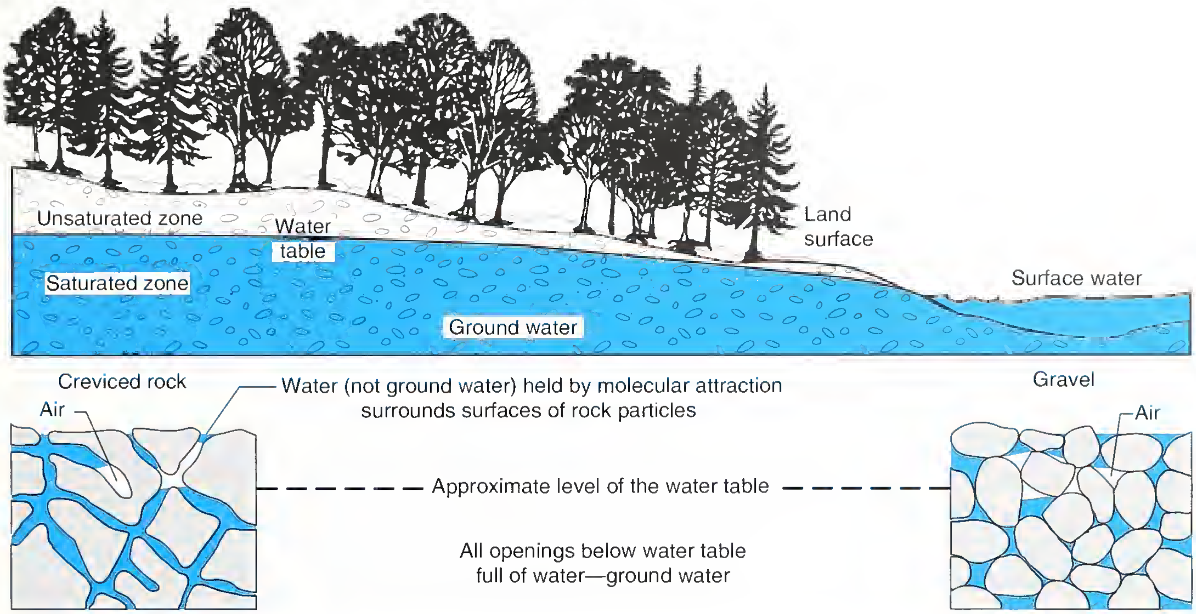
The policies being tested by the Initiative—education and technical and financial assistance—represent the "management solution" to the agriculture/water quality problem. Activities center around three Initiative objectives:

**Determine the precise relationship between agricultural activities and ground water quality.** Research is being funded to expand our knowledge of the factors and processes that control movement of agricultural chemicals from the field into the ground water. This information is being analyzed to provide insight on feasible solutions. State-of-the-art field equipment has been installed at sites around the country to monitor soil and water parameters, characterize the weather, and determine the effects of various crop management systems on water quality.

**Develop comprehensive, consistent, and periodic national data on agricultural chemicals, related farm practices, and links with the physical environment.** Surveys are being conducted by USDA to collect information on chemical use in agriculture—an important factor in identifying potential problem areas and feasible solutions. Two extensive data collection activities are underway: 1) a national survey to determine pesticide and fertilizer use levels for major crops, and 2) a regional chemical use and farming practice survey to aid in understanding the relationships among farming activities, characteristics of the physical environment (such as soil type, climate, and terrain), and ground water quality.

**Develop and transfer new technology and management practices that farmers can use.** USDA agencies and their state cooperators are developing and refining systems to help farmers assess their individual farm situations; to focus remedial or preventive efforts in areas of increased vulnerability; and to remedy those cases. Program emphasis is on nutrient and pesticide management to show farmers how to prevent field-applied agricultural chemicals from leaching beyond the root zone. "Demonstration" projects have been established around the country to demonstrate the feasibility of specific farm practices that will reduce chemical loadings from the field. New and modified management strategies are being developed at several research locations that reduce chemical loadings and are economically feasible. Education and technical assistance programs are being developed to accelerate the rate of adoption of new and modified farming systems.

## What is ground water?




Ground water is water under the Earth's surface that has saturated the pores and cracks in soil and rock.

When rain falls or snow melts, some of the water evaporates, some is transpired by plants, some flows overland and collects in streams, and the rest infiltrates into the pores or cracks of the soil and rock as ground water. The first water that enters the soil replaces water that has been evaporated or used by plants during a preceding dry period. The excess water infiltrates to the **water table**, which is defined as the top of the **saturated zone.** Below the water table, all the openings in the rocks are full of water. This saturated zone constitutes an **aquifer**. Aquifers are moderately to highly permeable rocks where ground water is stored. Ground water moves horizontally through the aquifer to wells from which water is being withdrawn, or to streams and springs.

The zone between the land surface and the aquifer water is called the **unstaturated zone**. In this zone, water is held mostly in smaller openings of the soil and rock by molecular attraction, and will flow. The larger openings usually contain water. After a significant rain, the zone may be almost saturated; after a long dry spell, it may be almost dry.

An aquifer may lie a few feet below the land surface to thousands of feet below. Shallow aquifers in areas of substantial precipitation may be replenished almost immediately. Deep aquifers, on the other hand, may be recharged very slowly, depending on the thickness and porosity of the unsaturated zone.

**Water table aquifers** are generally recharged locally, and water tables in shallow aquifers may fluctuate up and down directly in unison with precipitation or streamflow. Other aquifers are confined by layers of relatively impermeable rock and are called **artesian aquifers**. Artesian aquifers are an important source of drinking water. Recharge areas for artesian aquifers are usually some distance from a well site.

Agrichemicals are carried with the ground water as it infiltrates form the surface to the saturated zone. **This study focuses on shallow ground water in assessing the potential for ground water contamination.** Agrichemical residue has been most often found in wells drawing from shallow ground water sources. Shallow ground water also provides the base flow in rivers and streams. If contaminated, this ground water discharge can be an important source of chemical loading to streams, rivers, bays, and estuaries.

(Source: United States Department of Interior, Geological Survey. Ground Water. 1986, 23p.)

## Legislation to Protect Ground Water

Even though much remains to be learned about the extent of the ground water quality problem as it relates to agricultural chemical use, pressure has been put on lawmakers to pass legislation to "protect" the ground water resource from further contamination. Land retirement provisions related to water quality went into effect with the 1985 and 1990 Farm Bills. The Safe Drinking Water Act gives EPA the authority to set standards for drinking water. It includes a provision for a wellhead protection program administered by the States.

Most legislative activity targeted at ground water protection has been developed at the State level. Laws that could have an impact on ground water quality have been passed in 27 States. However, no State yet has a comprehensive legal framework for protecting ground water from all agricultural nonpoint source pollutants (Ribaudo and Woo 1991). Arizona, Iowa, California, and Nebraska have been more active than others in developing and implementing legislation to protect ground water.

# A National Perspective of the Factors Determining the Potential for Agrichemical Leaching

Leaching of agrichemicals through the soil and into the ground water depends on a host of factors and complex processes (OTA 1990). These include the natural characteristics of an area, the properties of the chemicals used, and the farm management practices. These factors can be grouped into two broad categories—intrinsic vulnerability factors and anthropogenic vulnerability factors.

Intrinsic vulnerability factors are the set of natural factors, such as climate and the propensity of soil to leach, that are in effect regardless of man's activities. Intrinsic factors vary considerably throughout the country. Information on intrinsic vulnerability, even in areas not presently farmed, is important for making decisions on future land use.

Anthropogenic vulnerability factors are producer activities, such as chemical use and irrigation, that have potential impact on leaching of agrichemicals. These factors are as geographically diverse as intrinsic factors. Chemical use, for example, depends on the pest problems the producer expects to encounter, which in turn depends on the type of crop that is grown and the local climate. The type of crop grown depends on characteristics of the land as well as a host of factors related to costs of production, output prices, and the existence and nature of government commodity programs.

The National distribution of some of these vulnerability factors is presented in this section. The next section presents methods for estimating vulnerability indexes that incorporate these factors, followed by an assessment of where in the country the ground water would be expected to be most at risk of contamination from use of agricultural chemicals, and where the risk is minimal.

## Analytical Framework

The 1982 National Resource Inventory (NRI) was used to develop an analytical framework. NRI's are based on a scientific, stratified random sampling design that permits extrapolation of point samples to totals for larger areas (see appendix A). About 800,000 sample points throughout the continental U.S. are included in the inventory. Information on nearly 200 attributes was collected at each NRI sample.point. Attributes included land use and cover, cropping history, conservation practices, potential cropland, highly eroding land, water and wind erosion estimates, wetlands; wildlife habitat, vegetative cover, and irrigation. Linkage between NRI and soils data bases allows additional soil characteristics and interpretations to be treated as attributes at the sample points.

The analytical framework was constructed by dividing the country (restricted to the 48 conterminous States) into small areas using a unique *geocode* for each area consisting of three geographic identifiers associated with each NRI sample point—county, MLRA, and hydrologic unit. About 27 million acres were excluded from the analytical framework because sample points could not be associated with the cartographic data base. The resulting analytical framework contained 13,353 geographic areas, each containing from 1 to 710 NRI sample points. The median number of NRI sample points per area was 34; 75 percent contained 12 or more points, and 25 percent contained 80 or more points. The correspondence between the full 1982 NRI data base and the analytical framework is shown in table 1. The analytical framework includes 97.6 percent of non-Federal rural land acres estimated for 1982 and 98.6 percent of the cropland acres. This analytical framework was used to calculate all numerical estimates presented in this publication.

A cartographic data base was created to describe the analytical framework. The 1982 NRI was embedded in a national cartographic data base using a Geographic Information System (GIS). The cartographic data base is described in appendix B.

## Soils Potential to Leach Pesticides

Soil characteristics are determined by the interaction of soil-forming factors. These factors include the soil's geologic parent material, the climate under which the soil formed, the nature of the vegetative cover, the kinds and abundance of soil organisms, and the amount of time the soil has been forming. The resulting soil properties in turn have a direct influence on how rapidly or slowly agrichemicals move through the soil and into ground water. These properties vary significantly throughout the country, and, thus, so does the potential for soil to leach agrichemicals.

The propensity for pesticides to leach past the root zone depends on the interaction of pesticide properties and soil properties. The most important properties have been incorporated into the Soil-Pesticide Interaction Screening Procedure (SPISP) (see appendix C). This procedure is used by the Soil Conservation Service to evaluate the potential for pesticide loss from a field by leaching. The SPISP generated a 4 by 4 matrix classifying the potential pesticide loss according to combinations of four pesticide leaching classes and four soil leaching classes (table 2). Pesticide loss potentials range from 4, indicating essentially no pesticide loss, to 1, which could possibly represent situations where 80 percent or more of the pesticide leaches past the root zone. The pesticide loss potentials were developed using the ground water leaching model GLEAMS to calculate pesticide loss below the root zone for 40,896 combinations of soil and pesticide properties.

The soil leaching class by itself does not determine the potential of the soil to leach pesticides—pesticide information is also required. Nevertheless, the soil leaching classes can be helpful indicators of the intrinsic potential for leaching. For example, soil belonging to the *Very Low Soil Leaching Class* has a pesticide loss potential of either 3 or 4, depending on the pesticide used. They are thus associated with a small chance of leaching pesticides past the root zone. In contrast, soil belonging to the *High Soil Leaching Class* varies from a high to a low probability of leaching, depending on the pesticide used.

The soil leaching class was determined at each NRI sample point in the analytical framework using site specific data on soil properties.

**Soils with high potential to leach pesticides**
Soils in the *High Soil Leaching Class* are predominantly in the Southeast, central plains, the Southwest, and northern Michigan (fig. 1). They comprise 20 percent (279 million acres) of the total non-Federal rural acreage.

**Table 1** Acreage by State of non-Federal rural land and cropland represented in the analytical framework

| | Non-Federal rural land | | | | | Cropland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1982 NRI data base | | Analytical framework | | | 1982 NRI data base | | Analytical framework | | |
| | Million acres | Percent of total | Number of NRI sample points | Million acres | % of NRI data base included | Million acres | Percent of total | Number of NRI sample points | Million acres | % of NRI data base included |
| Alabama | 29.697 | 2.1 | 16,940 | 29.159 | 98.2 | 4.510 | 1.1 | 2,912 | 4.476 | 99.2 |
| Arizona | 39.582 | 2.8 | 5,055 | 39.019 | 98.6 | 1.206 | 0.3 | 1,107 | 1.205 | 99.9 |
| Arkansas | 28.770 | 2.0 | 11,433 | 28.080 | 97.6 | 8.102 | 1.9 | 3,206 | 7.943 | 98.0 |
| California | 49.833 | 3.5 | 15,128 | 47.825 | 96.0 | 10.518 | 2.5 | 4,984 | 10.271 | 97.7 |
| Colorado | 41.271 | 2.9 | 13,883 | 39.063 | 94.7 | 10.603 | 2.5 | 4,490 | 10.064 | 94.9 |
| Connecticut | 2.401 | 0.2 | 2,330 | 2.310 | 96.2 | 0.245 | 0.1 | 271 | 0.244 | 99.7 |
| Delaware | 1.039 | 0.1 | 1,065 | 1.013 | 97.5 | 0.519 | 0.1 | 549 | 0.514 | 99.1 |
| Florida | 27.730 | 2.0 | 20,443 | 26.794 | 96.6 | 3.557 | 0.8 | 2,629 | 3.508 | 98.6 |
| Georgia | 32.536 | 2.3 | 19,933 | 32.122 | 98.7 | 6.568 | 1.6 | 3,964 | 6.536 | 99.5 |
| Idaho | 18.934 | 1.3 | 11,299 | 18.401 | 97.2 | 6.390 | 1.5 | 5,110 | 6.226 | 97.4 |
| Illinois | 32.076 | 2.3 | 28,064 | 31.652 | 98.7 | 24.727 | 5.9 | 21,384 | 24.540 | 99.2 |
| Indiana | 20.597 | 1.5 | 15,758 | 20.055 | 97.4 | 13.781 | 3.3 | 10,201 | 13.612 | 98.8 |
| Iowa | 33.709 | 2.4 | 21,896 | 33.358 | 99.0 | 26.441 | 6.3 | 16,990 | 26.221 | 99.2 |
| Kansas | 49.655 | 3.5 | 48,791 | 49.013 | 98.7 | 29.118 | 6.9 | 29,330 | 28.890 | 99.2 |
| Kentucky | 22.866 | 1.6 | 17,744 | 22.504 | 98.4 | 5.934 | 1.4 | 4,657 | 5.897 | 99.4 |
| Louisiana | 25.256 | 1.8 | 24,548 | 24.559 | 97.2 | 6.409 | 1.5 | 5,978 | 6.209 | 96.9 |
| Maine | 19.066 | 1.4 | 4,395 | 18.903 | 99.1 | 0.953 | 0.2 | 329 | 0.952 | 99.8 |
| Maryland | 5.173 | 0.4 | 7,175 | 5.077 | 98.2 | 1.794 | 0.4 | 2,432 | 1.788 | 99.6 |
| Massachusetts | 3.839 | 0.3 | 3,574 | 3.709 | 96.6 | 0.297 | 0.1 | 268 | 0.284 | 95.5 |
| Michigan | 30.265 | 2.1 | 21,944 | 29.653 | 98.0 | 9.443 | 2.2 | 8,154 | 9.359 | 99.1 |
| Minnesota | 45.036 | 3.2 | 34,405 | 44.098 | 97.9 | 23.024 | 5.5 | 22,163 | 22.791 | 99.0 |
| Mississippi | 27.063 | 1.9 | 17,648 | 26.731 | 98.8 | 7.415 | 1.8 | 4,845 | 7.340 | 99.0 |
| Missouri | 39.543 | 2.8 | 26,911 | 38.735 | 98.0 | 14.998 | 3.6 | 11,969 | 14.782 | 98.6 |
| Montana | 64.665 | 4.6 | 14,183 | 64.113 | 99.1 | 17.197 | 4.1 | 4,538 | 17.063 | 99.2 |
| Nebraska | 46.990 | 3.3 | 21,483 | 46.635 | 99.2 | 20.277 | 4.8 | 11,859 | 20.127 | 99.3 |
| Nevada | 9.788 | 0.7 | 6,233 | 9.530 | 97.4 | 0.860 | 0.2 | 1,054 | 0.815 | 94.8 |
| New Hampshire | 4.629 | 0.3 | 3,798 | 4.551 | 98.3 | 0.158 | 0.0 | 179 | 0.158 | 100.0 |
| New Jersey | 3.342 | 0.2 | 3,846 | 3.226 | 96.5 | 0.809 | 0.2 | 932 | 0.801 | 98.9 |
| New Mexico | 50.535 | 3.6 | 9,720 | 47.241 | 93.5 | 2.413 | 0.6 | 1,976 | 2.337 | 96.9 |
| New York | 27.386 | 1.9 | 16,854 | 26.557 | 97.0 | 5.912 | 1.4 | 4,079 | 5.786 | 97.9 |
| North Carolina | 26.481 | 1.9 | 15,196 | 26.065 | 98.4 | 6.695 | 1.6 | 3,759 | 6.663 | 99.5 |
| North Dakota | 41.021 | 2.9 | 19,992 | 40.688 | 99.2 | 27.039 | 6.4 | 13,340 | 26.839 | 99.3 |
| Ohio | 22.859 | 1.6 | 17,299 | 22.070 | 96.5 | 12.447 | 3.0 | 9,424 | 12.168 | 97.8 |
| Oklahoma | 40.795 | 2.9 | 20,845 | 37.979 | 93.1 | 11.568 | 2.7 | 5,817 | 11.110 | 96.0 |
| Oregon | 28.291 | 2.0 | 9,961 | 26.642 | 94.2 | 4.356 | 1.0 | 2,498 | 4.025 | 92.4 |
| Pennsylvania | 25.144 | 1.8 | 24,099 | 24.658 | 98.1 | 5.896 | 1.4 | 6,956 | 5.840 | 99.0 |
| Rhode Island | 0.508 | 0.0 | 1,134 | 0.497 | 97.8 | 0.027 | 0.0 | 72 | 0.027 | 100.0 |
| South Carolina | 16.681 | 1.2 | 19,512 | 16.322 | 97.8 | 3.579 | 0.9 | 4,520 | 3.512 | 98.1 |
| South Dakota | 44.506 | 3.2 | 19,534 | 43.851 | 98.5 | 16.947 | 4.0 | 9,107 | 16.781 | 99.0 |
| Tennessee | 23.189 | 1.6 | 19,323 | 22.846 | 98.5 | 5.592 | 1.3 | 5,120 | 5.570 | 99.6 |
| Texas | 157.431 | 11.2 | 63,712 | 154.239 | 98.0 | 33.320 | 7.9 | 14,305 | 32.718 | 98.2 |
| Utah | 16.247 | 1.2 | 5,374 | 15.992 | 98.4 | 2.039 | 0.5 | 1,635 | 2.037 | 99.9 |
| Vermont | 5.377 | 0.4 | 6,366 | 5.291 | 98.4 | 0.648 | 0.2 | 877 | 0.647 | 99.8 |
| Virginia | 21.292 | 1.5 | 19,547 | 20.446 | 96.0 | 3.397 | 0.8 | 3,126 | 3.229 | 95.1 |
| Washington | 28.462 | 2.0 | 11,794 | 27.677 | 97.2 | 7.793 | 1.9 | 3,926 | 7.681 | 98.6 |
| West Virginia | 13.722 | 1.0 | 12,643 | 13.565 | 98.9 | 1.093 | 0.3 | 1,041 | 1.087 | 99.5 |
| Wisconsin | 30.890 | 2.2 | 17,610 | 30.090 | 97.4 | 11.457 | 2.7 | 7,202 | 11.324 | 98.8 |
| Wyoming | 32.240 | 2.3 | 8,191 | 31.559 | 97.9 | 2.587 | 0.6 | 1,757 | 2.570 | 99.3 |
| **48 State Total** | **1,408.401** | **100.0** | **778,611** | **1,374.159** | **97.6** | **420.661** | **100.0** | **287,021** | **414.565** | **98.6** |

Over 30 percent of the soils in 16 States are in this leaching class—Alabama, Florida, Georgia, South Carolina, North Carolina, Virginia, and Delaware in the South and East; Wyoming, Colorado, and Nebraska in the central plains; Arizona and New Mexico in the Southwest; and Rhode Island and Michigan. West Texas and southern California also have significant acreage of soils in the *High Soil Leaching Class*. These areas are in the high risk group with respect to the intrinsic potential for leaching.

**Soils with intermediate potential to leach pesticides**
These soils comprise 27 percent of the total non-Federal rural acreage (376 million acres) and are generally more dispersed nationally than soils in other soil leaching classes (fig. 2). Soils in the *Intermediate Soil Leaching Class* can vary from a high probability of leaching (Potential 1) to no leaching, depending on the pesticides used. Significant concentrations occur in seven States—Kansas, Michigan, Wisconsin, and North Dakota in the North; and New Hampshire, Massachusetts, and Connecticut in the Northeast.

**Soils with low potential to leach pesticides**
The highest percentage of soils nationally falls in the *Low Soil Leaching Class*—30 percent (412 million acres) (fig. 3). The pesticide loss potentials range from Potential 2, where some leaching is expected, to Potential 4, where no leaching is expected. This soil leaching class is concentrated predominantly in the Midwest, the East, and along the West Coast. The majority of the soils in Iowa, Indiana, Illinois, Ohio, New York, and Pennsylvania are in this soil leaching class.

**Table 2** Pesticide loss potentials

| Soil leaching class | Pesticide leaching class: Large | Medium | Small | Extra small |
|---|---|---|---|---|
| High | 1 | 1 | 2 | 3 |
| Intermediate | 1 | 2 | 3 | 4 |
| Low | 2 | 3 | 3 | 4 |
| Very low | 3 | 3 | 4 | 4 |

**Soils with very low potential to leach pesticides**
Very little, if any, leaching of pesticides is expected in areas that have soils in this leaching class, regardless of the properties of the pesticides used. About 22 percent (306 million acres) of the non-Federal rural land have soils in the *Very Low Soil Leaching Class*. They tend to be concentrated in the South Central Lowlands and in the West (fig. 4). States that have a disproportionate amount of acreage in this class are Texas, Louisiana, Arkansas, and Mississippi in the South; California, Nevada, Arizona, Utah, and New Mexico in the Southwest; and South Dakota and Wyoming. Three of these States, Arizona, New Mexico, and Wyoming, were also listed with the States associated with the *High Soil Leaching Class*, demonstrating how diverse the intrinsic vulnerability for leaching of pesticides is even on a regional basis.

Although most areas of the country have some soils in the *Very Low Soil Leaching Class*, two areas are nearly devoid of these soils—an area in the Midwest extending from Iowa through central Illinois and Indiana and including much of Michigan, and another area near the Appalachian Mountains. Less than 4 percent of the soils in Iowa, Indiana, Michigan, Rhode Island, and Connecticut are in the *Very Low Soil Leaching Class* (table 3). This is significant in the Midwest because of the high level of agricultural activity, and indicates that the leaching properties of the chemicals used in those areas is a predominant factor in determining pesticide leaching.

**Table 3** Percent of non-Federal rural land with soils in each of the four soil leaching classes in the Soil-Pesticide Interaction Screening Procedure

| | Non-Federal rural land (million acres) | Soil leaching class | | | |
|---|---|---|---|---|---|
| | | % High | % Intermediate | % Low | % Very low |
| Alabama | 29.159 | 33.9 | 24.9 | 17.3 | 23.9 |
| Arizona | 39.019 | 40.1 | 10.4 | 6.9 | 42.6 |
| Arkansas | 28.080 | 16.9 | 11.9 | 35.1 | 36.1 |
| California | 47.825 | 19.5 | 21.7 | 24.6 | 34.3 |
| Colorado | 39.063 | 40.5 | 19.9 | 21.8 | 17.8 |
| Connecticut | 2.310 | 29.4 | 49.7 | 16.9 | 4.0 |
| Delaware | 1.013 | 32.9 | 33.0 | 22.2 | 11.8 |
| Florida | 26.794 | 30.7 | 26.5 | 26.4 | 16.4 |
| Georgia | 32.122 | 46.5 | 27.3 | 14.0 | 12.1 |
| Idaho | 18.401 | 10.4 | 38.2 | 36.3 | 15.1 |
| Illinois | 31.652 | 7.7 | 18.5 | 64.7 | 9.1 |
| Indiana | 20.055 | 8.6 | 28.6 | 59.3 | 3.4 |
| Iowa | 33.358 | 2.1 | 28.7 | 66.4 | 2.8 |
| Kansas | 49.013 | 10.0 | 48.5 | 23.9 | 17.6 |
| Kentucky | 22.504 | 3.8 | 36.8 | 47.9 | 11.5 |
| Louisiana | 24.559 | 6.7 | 10.6 | 24.3 | 58.4 |
| Maine | 18.903 | 9.7 | 33.4 | 33.7 | 23.2 |
| Maryland | 5.077 | 14.3 | 39.5 | 35.6 | 10.7 |
| Massachusetts | 3.709 | 21.1 | 50.1 | 14.8 | 14.1 |
| Michigan | 29.653 | 35.4 | 43.2 | 17.7 | 3.7 |
| Minnesota | 44.098 | 12.0 | 39.6 | 41.8 | 6.7 |
| Mississippi | 26.731 | 9.0 | 25.4 | 36.9 | 28.8 |
| Missouri | 38.735 | 9.8 | 29.6 | 43.5 | 17.2 |
| Montana | 64.113 | 17.0 | 27.2 | 32.6 | 23.2 |
| Nebraska | 46.635 | 43.4 | 36.9 | 9.8 | 9.9 |
| Nevada | 9.530 | 20.4 | 19.7 | 25.9 | 34.0 |
| New Hampshire | 4.551 | 28.3 | 48.2 | 18.9 | 4.6 |
| New Jersey | 3.226 | 17.8 | 36.2 | 31.1 | 14.8 |
| New Mexico | 47.241 | 36.5 | 17.1 | 10.2 | 36.2 |
| New York | 26.557 | 6.2 | 26.3 | 57.2 | 10.3 |
| North Carolina | 26.065 | 35.4 | 27.2 | 20.2 | 17.2 |
| North Dakota | 40.688 | 6.0 | 42.8 | 38.1 | 13.0 |
| Ohio | 22.070 | 1.4 | 18.6 | 67.4 | 12.6 |
| Oklahoma | 37.979 | 23.0 | 31.2 | 23.8 | 21.9 |
| Oregon | 26.642 | 7.9 | 20.8 | 44.0 | 27.2 |
| Pennsylvania | 24.658 | 7.9 | 36.3 | 50.0 | 5.9 |
| Rhode Island | 0.497 | 37.9 | 32.9 | 25.4 | 3.8 |
| South Carolina | 16.322 | 37.5 | 26.1 | 17.4 | 19.0 |
| South Dakota | 43.851 | 11.0 | 30.1 | 23.5 | 35.3 |
| Tennessee | 22.846 | 14.1 | 40.0 | 30.9 | 15.1 |
| Texas | 154.239 | 21.8 | 16.7 | 20.4 | 41.0 |
| Utah | 15.992 | 18.6 | 24.3 | 23.4 | 33.6 |
| Vermont | 5.291 | 7.4 | 30.8 | 45.9 | 16.0 |
| Virginia | 20.446 | 33.3 | 25.3 | 33.6 | 7.7 |
| Washington | 27.677 | 12.6 | 37.4 | 36.4 | 13.7 |
| West Virginia | 13.565 | 14.0 | 26.5 | 48.0 | 11.5 |
| Wisconsin | 30.090 | 24.6 | 42.3 | 27.2 | 6.0 |
| Wyoming | 31.559 | 30.5 | 17.1 | 17.4 | 34.9 |
| **48 State Total** | 1,374.159 | 20.3 | 27.4 | 30.0 | 22.3 |

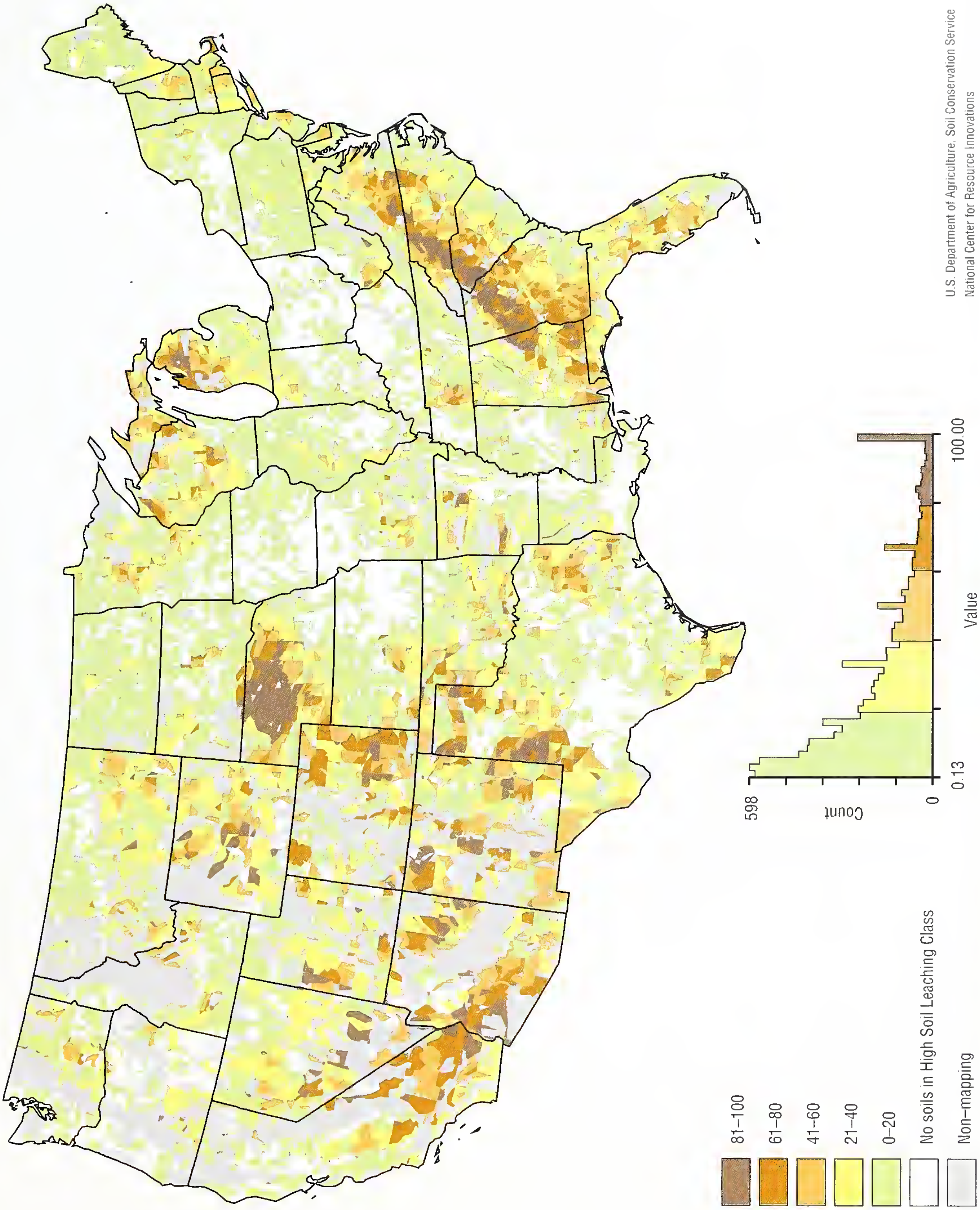



**Figure 1** Percent area with soils that have a *High Soil Leaching Class* (for pesticides)

## About the Maps in this Publication

A cartographic data base was used to construct the maps in this publication. Appendix B describes the data base and how it was developed, including a map showing the polygon boundaries.

The three basic types of maps in this publication are:

- **Percent Area Maps**—These maps present the percent area of each polygon that meets a specified criterion. An example is figure 1, which shows the percent area with soils that have a *High Soil Leaching Class*. This map was made by first determining which NRI points in each polygon met the criterion for being in a *High Soil Leaching Class,* then summing the expansion factors (in acres) for those points, and finally dividing by the sum of the expansion factors of all the points in the polygon. The denominator in this case represents the total acres of non-Federal rural land associated with the polygon. The percentages were grouped into five classes, and each polygon was assigned a color depending on the class determined for the percentage associated with the polygon. Where the title reads “percentage of cropland area with ...,” the percent area is calculated on the basis of only the cropland points in the polygon.

- **Average Value Maps**—The average value of an attribute of the NRI points in a polygon is used to represent the entire polygon in some maps. An example is figure 5, titled "Average percolation factor." For all of these maps, the expansion factors for the NRI points in the polygon were used as weights in the calculation of the average because the sample points do not all represent the same number of acres. In most cases, the area-weighted average was based on all the NRI sample points in the polygons, but in a few cases the weighted average was based on cropland acres only.

- **Total Value Maps**—The total value of an attribute of the NRI points in a polygon was used in a few cases to represent the polygon. Figures 7 and 8, for example, show the total expenses for agrichemicals by county.

The 1982 NRI was not designed to provide statistically reliable estimates for areas as small as most of the polygons comprising the cartographic data base. The purpose of mapping these polygon-level statistics is to reveal the spatial trends in the data. Caution should therefore be taken in making interpretations from the map at the county and sub-county levels.

**Figure 2** Percent area with soils that have an *Intermediate Soil Leaching Class* (for pesticides)

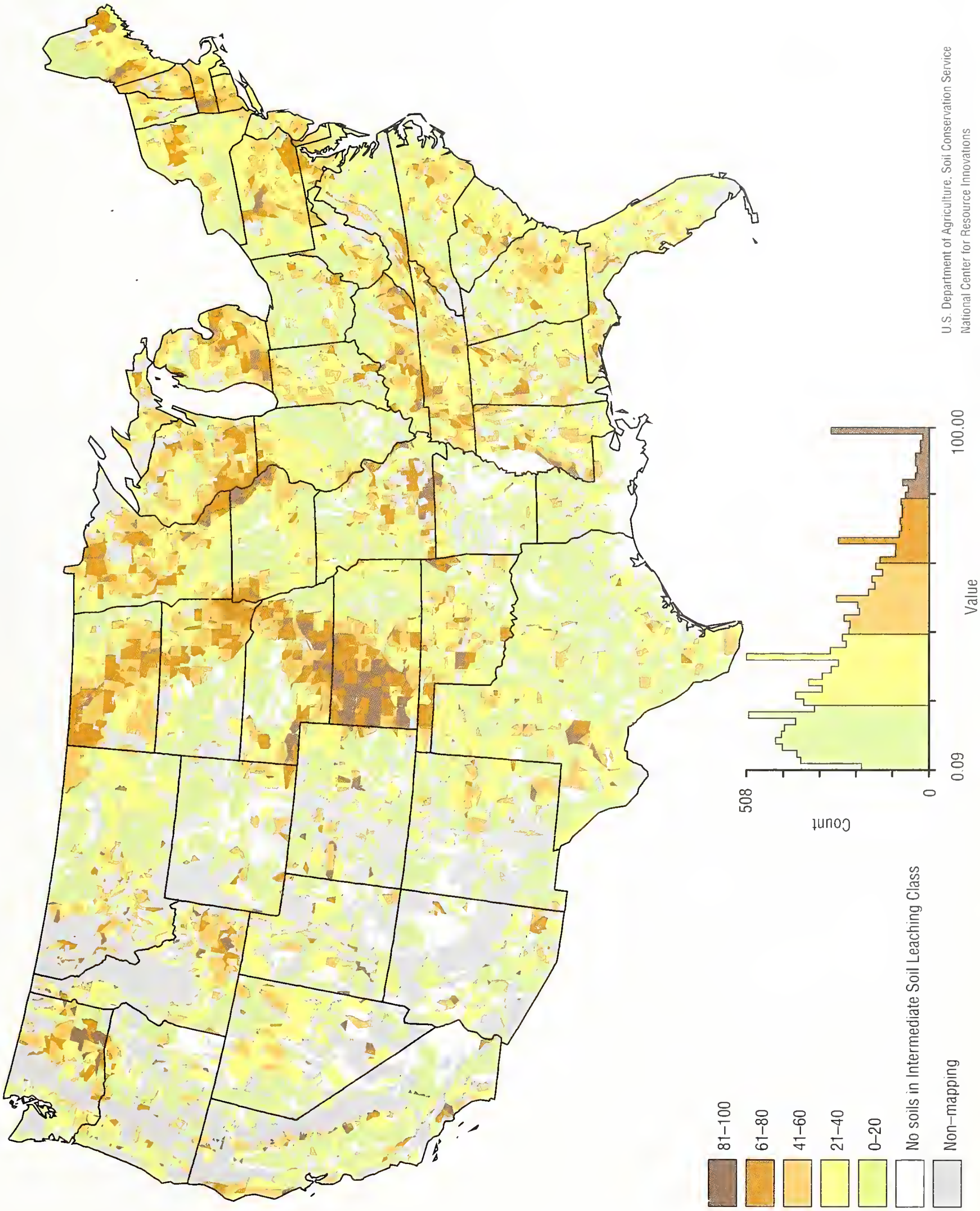


**Figure 3** Percent area with soils that have a *Low Soil Leaching Class* (for pesticides)

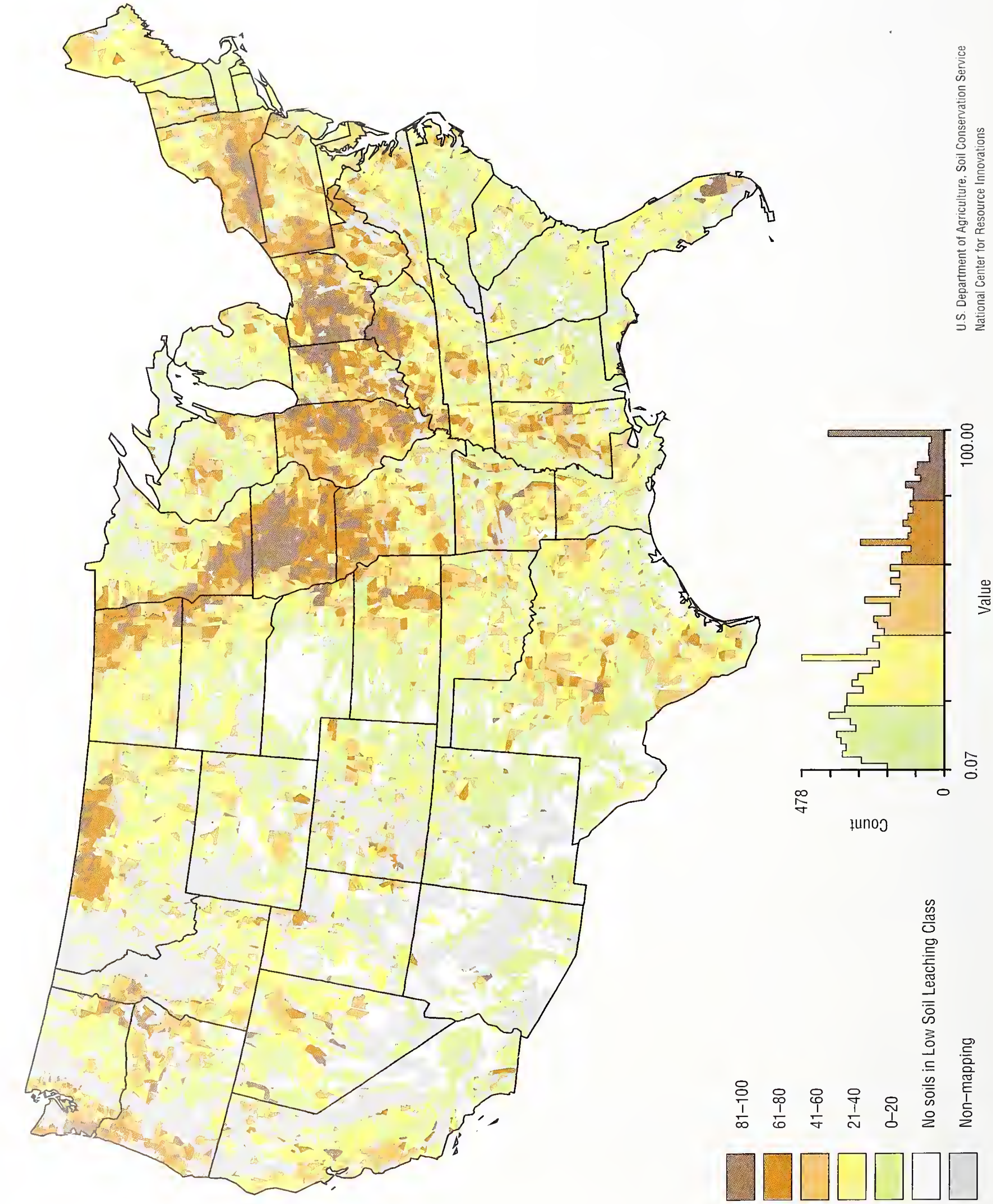
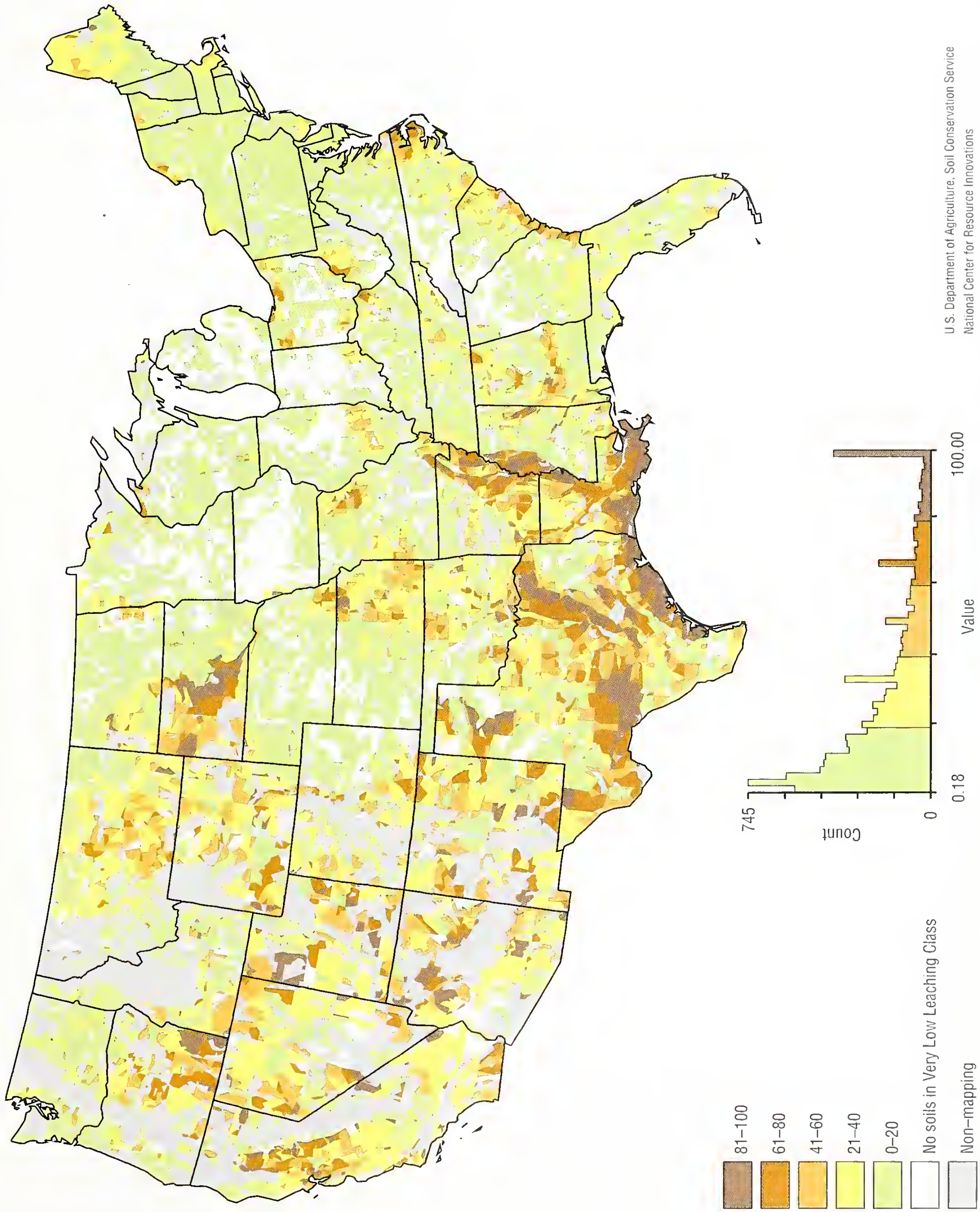


**Figure 4** Percent area with soils that have a *Very Low Soil Leaching Class* (for pesticides)



## Soils Potential to Leach Nitrates

Nitrate is a naturally occurring form of nitrogen in water bodies, and leaching of nitrates is a naturally occurring phenomenon. Unlike most pesticides, nitrate is highly soluble in water. Nitrate leaches past the root zone of even unfertilized lands. The amount of nitrates that leach into ground water depends on the amount and timing of rainfall, soil composition, soil permeability and porosity, time of the year, vegetation management, and the amount of nitrogen fertilizer applied.

Williams and Kissel (1991) developed a simple nitrate leaching index for use in identifying potential problem areas using an approach similar to that used to develop the SPISP. The index is essentially a measure of annual percolation past the root zone. It is a function of annual precipitation, timing of precipitation, and water storage capacity of the soil. Soils that have low storage capacity and high saturated conductivity (hydrologic group A) have a large percolation potential when rainfall is high. Winter rainfall is more likely to percolate than growing season rainfall because evapotranspiration is low during the winter. Little or no percolation occurs in areas of the country with low annual rainfall.

The Williams and Kissel nitrate leaching index was modified slightly for use as a climatic modifier for the SPISP (see appendix D) and called the "percolation factor." Modifications included adding the value 1 to eliminate zero values and an adjustment for irrigation that was designed to raise the relative ranking of irrigated areas to a par with rainfed farming in the Midwest.

Using data on annual precipitation, hydrologic soil group, and seasonal rainfall distribution, a Percolation Factor (PF) was determined for each NRI sample point. Precipitation data were imputed to NRI sample points on the basis of the proximity of the NRI point to one of over 7,000 weather stations throughout the country.

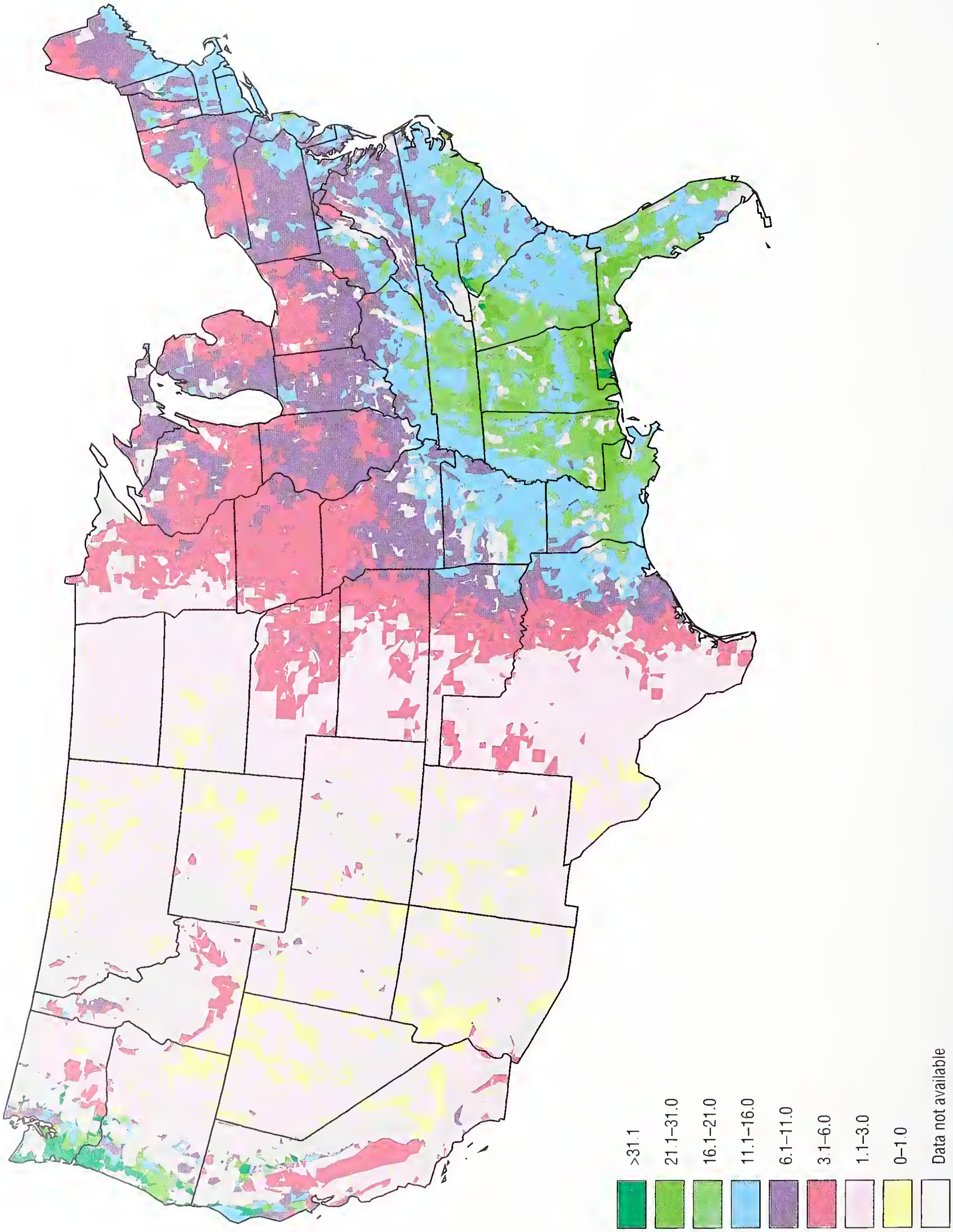
The National distribution of the percolation factor (fig. 5) shows areas of the country with different degrees of intrinsic vulnerability to nitrate leaching. Areas where PF exceeds 11 were considered by Williams and Kissel to have the potential for significant nitrate leaching if other risk factors were present. These areas are concentrated in the Southeast, along the East Coast, and along the West Coast north of San Francisco. In all, 22 percent (303 million acres) of the non-Federal rural land has a PF greater than 11 (table 4).

The majority of the area in the West and in the Great Plains has nearly negligible percolation factors. Nationally, 45 percent of the non-Federal rural land has PF scores less than 3.

**Table 4** Distribution of non-Federal rural land by State according to percolation factor scores

| | Percolation factor < 3 million acres | % | Percolation factor >11 million acres | % | | Percolation factor < 3 million acres | % | Percolation factor > 11 million acres | % |
|---|---|---|---|---|---|---|---|---|---|
| Alabama | 0.003 | 0.0 | 28.487 | 97.7 | Nebraska | 30.680 | 65.8 | 0.000 | 0.0 |
| Arizona | 38.517 | 98.7 | 0.000 | 0.0 | Nevada | 9.460 | 99.3 | 0.000 | 0.0 |
| Arkansas | 0.065 | 0.2 | 16.421 | 58.5 | New Hampshire | 0.000 | 0.0 | 1.598 | 35.1 |
| California | 35.033 | 73.3 | 6.653 | 13.9 | New Jersey | 0.005 | 0.2 | 1.952 | 60.5 |
| Colorado | 38.580 | 98.8 | 0.002 | 0.0 | New Mexico | 47.236 | 100.0 | 0.000 | 0.0 |
| Connecticut | 0.000 | 0.0 | 1.901 | 82.3 | New York | 1.238 | 4.7 | 5.414 | 20.4 |
| Delaware | 0.003 | 0.3 | 0.615 | 60.7 | North Carolina | 0.030 | 0.1 | 18.937 | 72.7 |
| Florida | 0.047 | 0.2 | 24.179 | 90.2 | North Dakota | 40.550 | 99.7 | 0.000 | 0.0 |
| Georgia | 0.004 | 0.0 | 26.794 | 83.4 | Ohio | 0.812 | 3.7 | 0.630 | 2.9 |
| Idaho | 15.762 | 85.7 | 0.215 | 1.2 | Oklahoma | 12.717 | 33.5 | 3.589 | 9.4 |
| Illinois | 0.322 | 1.0 | 1.480 | 4.7 | Oregon | 15.245 | 57.2 | 8.934 | 33.5 |
| Indiana | 0.034 | 0.2 | 3.685 | 18.4 | Pennsylvania | 0.030 | 0.1 | 5.202 | 21.1 |
| Iowa | 1.390 | 4.2 | 0.099 | 0.3 | Rhode Island | 0.001 | 0.1 | 0.346 | 69.6 |
| Kansas | 30.173 | 61.6 | 0.013 | 0.0 | South Carolina | 0.000 | 0.0 | 10.904 | 66.8 |
| Kentucky | 0.016 | 0.1 | 13.375 | 59.4 | South Dakota | 43.397 | 99.0 | 0.000 | 0.0 |
| Louisiana | 0.000 | 0.0 | 22.425 | 91.3 | Tennessee | 0.006 | 0.0 | 20.580 | 90.1 |
| Maine | 0.007 | 0.0 | 3.652 | 19.3 | Texas | 107.132 | 69.5 | 10.528 | 6.8 |
| Maryland | 0.004 | 0.1 | 2.380 | 46.9 | Utah | 15.522 | 97.1 | 0.000 | 0.0 |
| Massachusetts | 0.005 | 0.1 | 1.883 | 50.8 | Vermont | 0.027 | 0.5 | 1.297 | 24.5 |
| Michigan | 2.950 | 9.9 | 2.539 | 8.6 | Virginia | 0.031 | 0.2 | 9.184 | 44.9 |
| Minnesota | 19.929 | 45.2 | 0.000 | 0.0 | Washington | 16.426 | 59.4 | 8.264 | 29.9 |
| Mississippi | 0.000 | 0.0 | 25.924 | 97.0 | West Virginia | 0.017 | 0.1 | 5.029 | 37.1 |
| Missouri | 0.296 | 0.8 | 7.090 | 18.3 | Wisconsin | 4.702 | 15.6 | 0.310 | 1.0 |
| Montana | 62.915 | 98.1 | 0.000 | 0.0 | Wyoming | 31.527 | 99.9 | 0.000 | 0.0 |
| | | | | | **48 State Total** | 622.841 | 45.3 | 302.508 | 22.0 |

**Figure 5** Average percolation factor




**Note**: Average is area-weighted.

U.S. Department of Agriculture, Soil Conservation Service
National Center for Resource Innovations

# Farming Activities and Chemical Use

Ultimately, whether or not ground water contamination occurs in areas that have an intrinsic potential for leaching depends on the activities of agricultural producers. The principal activities that influence the potential for ground water contamination by agrichemicals are:

- pesticide use
- commercial fertilizer use
- irrigation and chemigation

Although farming has become more concentrated as farm numbers have declined, U.S. agriculture still varies widely in farm size, scale, resource use, and product mix. The farm sector is composed of more than 2 million farms that have resource holdings ranging from a few hundred dollars of investment to multimillion-dollar businesses controlling thousands of acres and employing many workers in multiple enterprises. Farm enterprises range from production of a single specialty crop, like blueberries or tomatoes, to operations producing a wide assortment of products. Some farmers make production decisions based on sales to nearby urban markets, while others react to world supply and demand conditions (Sommer & Hines 1991).

This diversity in farming operations produces substantial variation in the kind and amount of chemicals used in agriculture from State to State, from county to county, and from field to field.

Cropping activities put ground water most at risk. According to the 1982 NRI, about 30 percent of the non-Federal rural land (421 million acres) is cropland. Cropland is defined for purposes of the NRI as land used for the production of crops for harvest, including row crops, small-grain crops, hay crops, nursery crops, orchard crops, and other specialty crops. The land may be used continuously for these crops, or the crops may be grown in rotation with grasses and legumes.

Cropland is widely dispersed, but heaviest concentrations are in the Midwest, the Great Plains, along the Mississippi Valley in the South, and in irrigated regions in the West (fig. 6). In Illinois, Indiana, Iowa, and North Dakota, over two-thirds of the non-Federal rural land is cropland (table 1). Other States with over 50 percent cropland are Kansas, Ohio, Minnesota, and Delaware. While significant acreage of cropland occurs in the Eastern States, it is mixed with other land cover types and is less dense. States that have very little cropland (5 percent or less of non-Federal rural area in the State) are Arizona, New Hampshire, Maine, and New Mexico.

## Pesticide Use

According to the 1987 Agriculture Census, $4.7 billion was spent in 1987 by agricultural producers on agrichemicals, excluding fertilizer (US DOC 1990). Herbicides are the predominant pesticide, accounting for 85 percent, by volume, of the pesticides used on major field crops (USDA ERS 1991). Herbicides are used on more than 90 percent of corn, cotton, rice, and soybean acres and 75 percent of vegetable acres (USDA NASS 1991).

Insecticides account for about 13 percent of total pesticide use on major field crops; fungicides account for about 2 percent. Insecticides are used in production of 84 percent of vegetable acres, 35 percent of corn acres, 60 percent of cotton acres, and 85 percent of tobacco (USDA, ERS 1991, NASS 1991; Osteen and Szmedra 1989). Fungicides are used extensively in peanut and potato production and for fruits and vegetables.

Among the field crops, corn and soybeans account for the largest amount of pesticides used, followed by cotton, wheat, grain sorghum, and rice. Significant amounts are also used on barley, oats, peanuts, and tobacco.

Highest levels of pesticide expenditures are in Florida, California, Washington, the Mississippi River Valley, and the Midwest (fig. 7).

Pesticide expenditures correspond closely to enterprise type. Sommer and Hines (1991) identified 12 categories of farm operations that they used to reveal patterns of spatial diversity in agriculture across the country. Each county was associated with one of the 12 categories based on 1987 Agriculture Census county-level data on farm output type, farm resources, and farm-nonfarm linkages. The two clusters of coun-

**Figure 6** Percent area in cropland

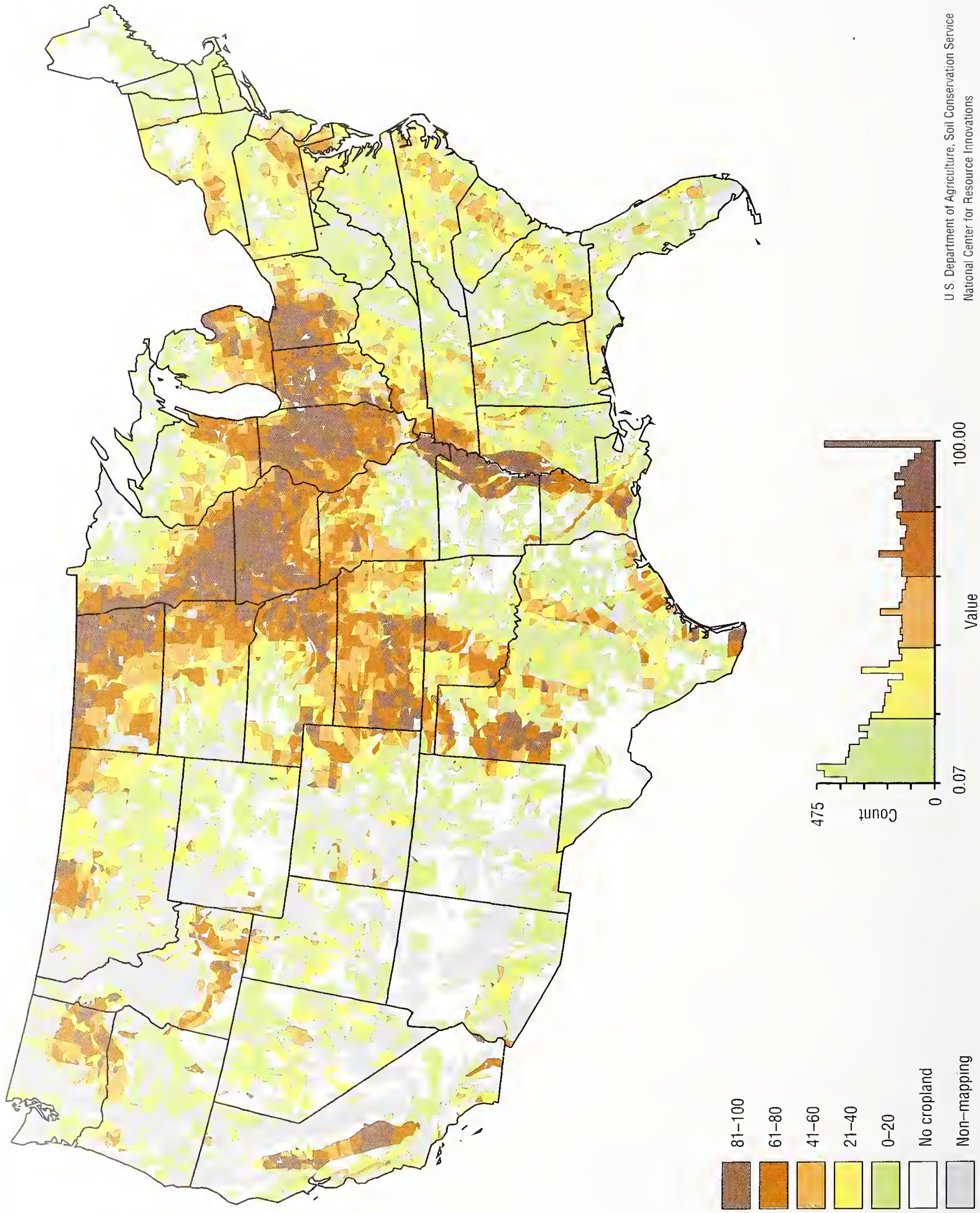
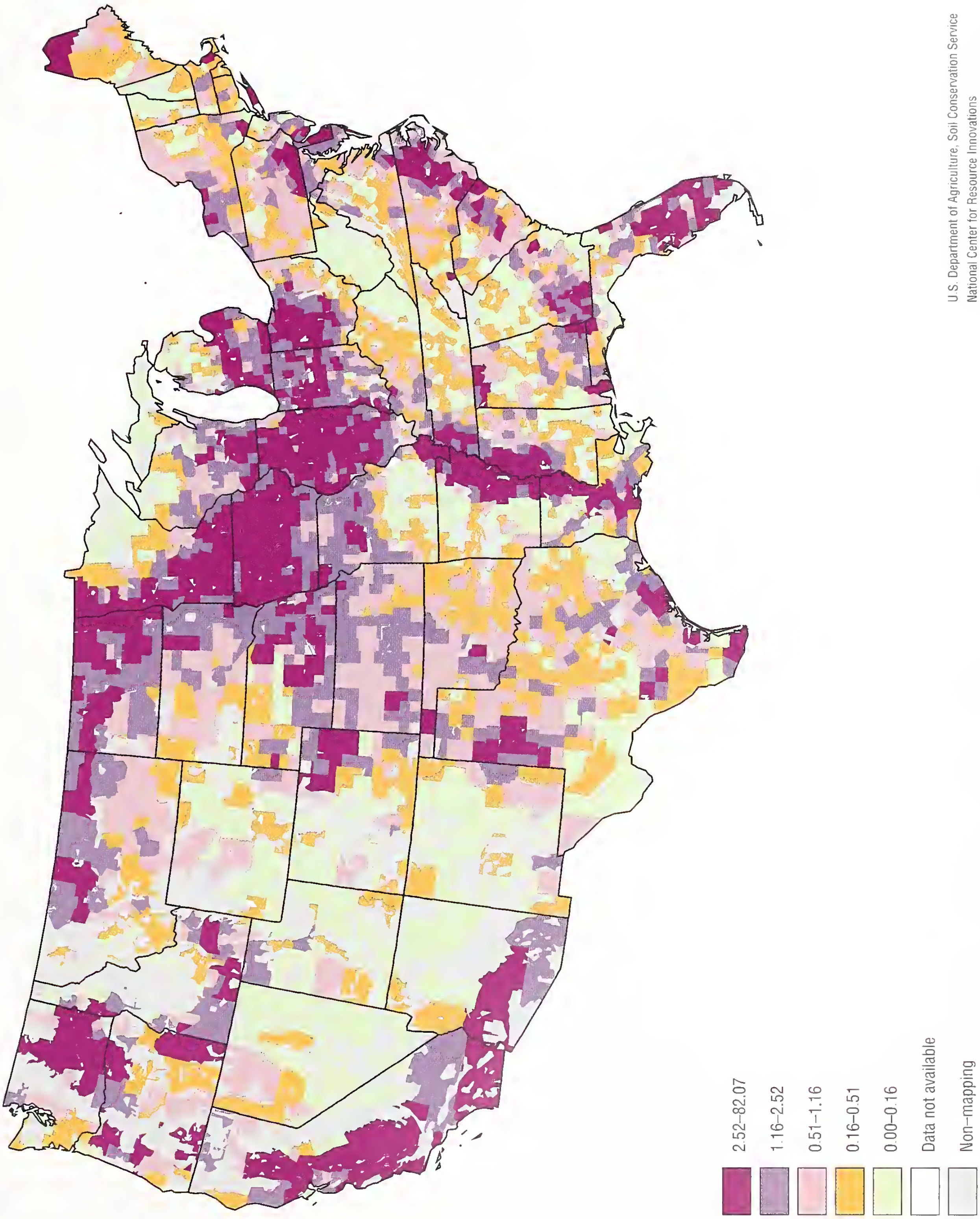


**Figure 7** Millions of dollars spent for agricultural chemicals excluding fertilizer (by county)



ties with the highest per-acre chemical expenses are 1) fruit and 2) vegetables and nursery products (table 5). The next highest per acre chemical expenses are associated with three crop clusters: 1) cotton; 2) corn, soybeans, and hogs; and 3) other crops. These five clusters together represent 70 percent of agrichemical sales while constituting only 35 percent of the farmland nationally. In contrast, the three clusters with the lowest per acre expenses on agricultural chemicals represent only 14 percent of agrichemical sales, but 47 percent of farmland nationally. These clusters are 1) cattle, wheat, and sorghum; 2) part-time cattle; and 3) sheep, cattle, and other livestock.

## Fertilizer Use

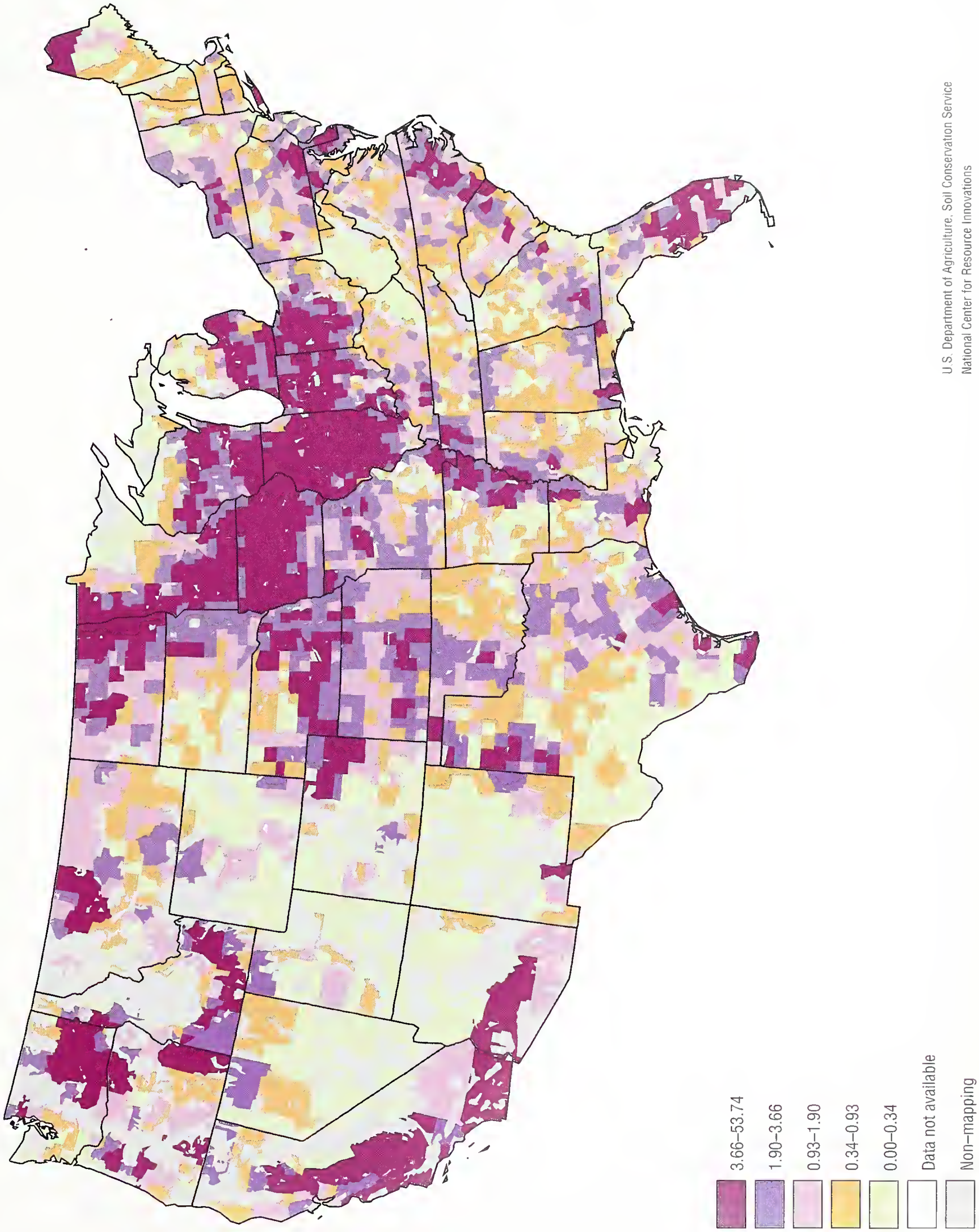
Agricultural producers spend more on commercial fertilizers than on pesticides—$6.7 billion dollars in 1987 (US DOC 1990). The primary fertilizer constituents are nitrogen, phosphate, and potash. Of these, nitrogen accounts for roughly half of the use (USDA ERS 1991). Commercial fertilizers are used on most field crops. Nitrogen is applied to over 90 percent of corn, cotton, potatoes, and rice, and over 60 percent of wheat acres. Phosphate and potash fertilizers are applied extensively to vegetables, corn, rice, and wheat (USDA NASS 1991).

The national distribution of commercial fertilizer expenses is shown in figure 8. Areas of greatest use correspond closely to areas where pesticide expenses are also high (table 5). States that have the highest quantities of nitrogen use are Iowa, Illinois, Nebraska, and Texas (USDA ERS 1991).

**Table 5** Agricultural chemical expenditures according to 12 farming-defined county clusters (Sommer and Hines 1991)

| Farming-defined county clusters | | Number of counties | % total farmland | Pesticide expense $ millions | Pesticide expense % of total | Pesticide expense $/farmland acre | Commercial fertilizer expense $ millions | Commercial fertilizer expense % of total | Commercial fertilizer expense $/farmland acre |
|---|---|---|---|---|---|---|---|---|---|
| Cluster 1: | Corn, soybeans, and hogs | 605 | 17.1 | 1,383 | 29.6 | 8.49 | 2,305 | 34.5 | 14.15 |
| Cluster 2: | Poultry | 316 | 3.7 | 151 | 3.2 | 4.30 | 292 | 4.4 | 8.31 |
| Cluster 3: | Dairy | 231 | 4.5 | 238 | 5.1 | 5.52 | 531 | 7.9 | 12.31 |
| Cluster 4: | Cattle, wheat, and sorghum | 370 | 27.5 | 443 | 9.5 | 1.69 | 715 | 10.7 | 2.72 |
| Cluster 5: | Tobacco | 175 | 2.0 | 105 | 2.2 | 5.39 | 222 | 3.3 | 11.39 |
| Cluster 6: | Part-time cattle | 476 | 12.1 | 156 | 3.3 | 1.35 | 345 | 5.2 | 2.99 |
| Cluster 7: | Fruit | 48 | 2.5 | 468 | 10.0 | 19.64 | 323 | 4.8 | 13.58 |
| Cluster 8: | Other crops | 135 | 4.9 | 361 | 7.7 | 7.69 | 506 | 7.6 | 10.76 |
| Cluster 9: | Vegetables and nursery | 277 | 5.6 | 650 | 13.9 | 12.11 | 746 | 11.2 | 13.91 |
| Cluster 10: | Wheat, oats, and other grains | 125 | 7.7 | 276 | 5.9 | 3.76 | 348 | 5.2 | 4.75 |
| Cluster 11: | Cotton | 124 | 4.7 | 412 | 8.8 | 9.24 | 310 | 4.6 | 6.96 |
| Cluster 12: | Sheep, cattle, and other livestock | 90 | 7.7 | 36 | 0.8 | 0.49 | 45 | 0.7 | 0.62 |

**Figure 8** Millions of dollars spent for commercial fertilizer (by county)



## Irrigation

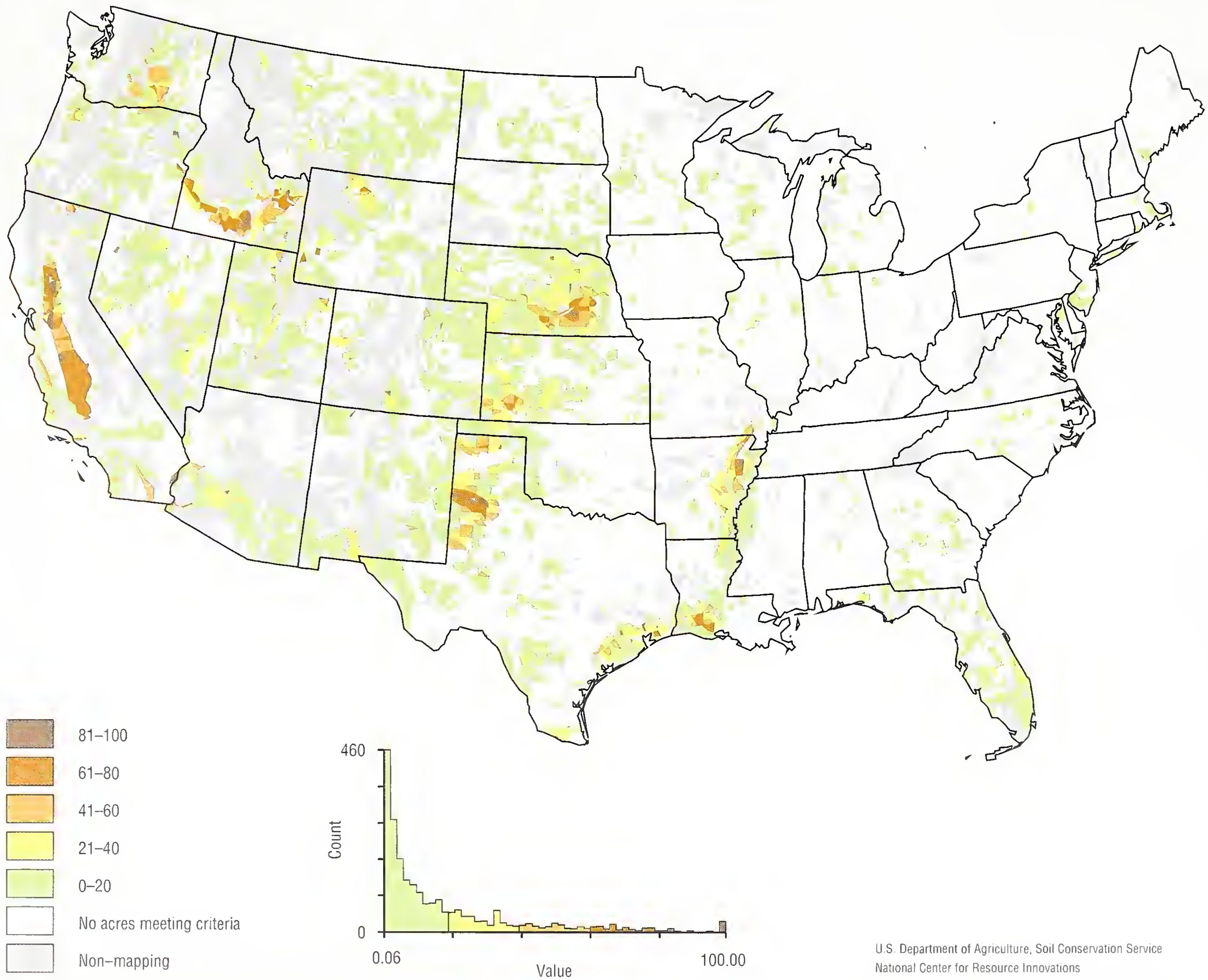
Of the non-Federal rural land, 4 percent (55 million acres) had half or more of water requirements supplied by irrigation in 1982 (table 6). All rice acreage and over 85 percent of orchard acreage is irrigated (Gollehon 1990). About 60 percent of vegetable and potato acreage is irrigated. Corn for grain, which uses large amounts of agrichemicals, is grown on about 20 percent of the total irrigated land. Substantial acreage of pasture and alfalfa are also irrigated. Most of the irrigated areas are in five States—California, Texas, Nebraska, Idaho, and Kansas (fig. 9).

Using irrigation systems to apply chemicals (chemigation) further increases the risk of ground water contamination. Most irrigation systems and a wide variety of chemicals are suited to chemigation. Chemigation has become a relatively common practice. In 1984 about 25 percent of the national potato acreage, for example, was on farms applying fertilizer through irrigation. Chemigation practices are expected to increase (Gollehon 1991).

**Table 6** Acreage where irrigation supplied more than a half of the water requirements in 1982

| | Million acres | Percent of non-Federal rural land | Percent of all irrigated acres |
|---|---|---|---|
| Alabama | 0.008 | 0.0 | 0.0 |
| Arizona | 1.247 | 3.2 | 2.2 |
| Arkansas | 2.184 | 7.8 | 3.9 |
| California | 9.471 | 19.8 | 17.1 |
| Colorado | 3.165 | 8.1 | 5.7 |
| Connecticut | 0.003 | 0.1 | 0.0 |
| Delaware | 0.000 | 0.0 | 0.0 |
| Florida | 1.421 | 5.3 | 2.6 |
| Georgia | 0.233 | 0.7 | 0.4 |
| Idaho | 3.998 | 21.7 | 7.2 |
| Illinois | 0.093 | 0.3 | 0.2 |
| Indiana | 0.027 | 0.1 | 0.0 |
| Iowa | 0.008 | 0.0 | 0.0 |
| Kansas | 3.177 | 6.5 | 5.7 |
| Kentucky | 0.000 | 0.0 | 0.0 |
| Louisiana | 1.192 | 4.9 | 2.1 |
| Maine | 0.005 | 0.0 | 0.0 |
| Maryland | 0.010 | 0.2 | 0.0 |
| Massachusetts | 0.011 | 0.3 | 0.0 |
| Michigan | 0.069 | 0.2 | 0.1 |
| Minnesota | 0.261 | 0.6 | 0.5 |
| Mississippi | 0.310 | 1.2 | 0.6 |
| Missouri | 0.165 | 0.4 | 0.3 |
| Montana | 2.494 | 3.9 | 4.5 |
| Nebraska | 6.961 | 14.9 | 12.6 |
| Nevada | 1.021 | 10.7 | 1.8 |
| New Hampshire | 0.000 | 0.0 | 0.0 |
| New Jersey | 0.026 | 0.8 | 0.0 |
| New Mexico | 1.380 | 2.9 | 2.5 |
| New York | 0.006 | 0.0 | 0.0 |
| North Carolina | 0.031 | 0.1 | 0.1 |
| North Dakota | 0.202 | 0.5 | 0.4 |
| Ohio | 0.008 | 0.0 | 0.0 |
| Oklahoma | 0.600 | 1.6 | 1.1 |
| Oregon | 1.911 | 7.2 | 3.4 |
| Pennsylvania | 0.001 | 0.0 | 0.0 |
| Rhode Island | 0.001 | 0.2 | 0.0 |
| South Carolina | 0.000 | 0.0 | 0.0 |
| South Dakota | 0.431 | 1.0 | 0.8 |
| Tennessee | 0.001 | 0.0 | 0.0 |
| Texas | 8.350 | 5.4 | 15.1 |
| Utah | 1.559 | 9.8 | 2.8 |
| Vermont | 0.000 | 0.0 | 0.0 |
| Virginia | 0.011 | 0.1 | 0.0 |
| Washington | 1.670 | 6.0 | 3.0 |
| West Virginia | 0.000 | 0.0 | 0.0 |
| Wisconsin | 0.228 | 0.8 | 0.4 |
| Wyoming | 1.514 | 4.8 | 2.7 |
| **48 State Total** | 55.461 | 4.0 | 100.0 |

**Figure 9** Percent area where irrigation supplies more than a half of the water requirements



# Measuring Ground Water Vulnerability

Areas of the country that have a ground water contamination problem associated with leaching of agrichemicals are those that have both intrinsic and anthropogenic risk factors present. Ground water vulnerability indexes were developed for pesticides and nitrogen fertilizer to help identify these areas.

The natural processes involved in agrichemical leaching include biological, physical, and chemical interactions that are too complex to incorporate fully in a vulnerability measure for use at the National level. Instead, vulnerability was based on three principal factors required for contamination of ground water to occur:

- The propensity of soils to leach pesticides and nitrates.
- The amount and timing of rainfall, which is required to carry the chemicals through the soil and to the water table.
- The extent of chemical use.

The vulnerability indexes were derived to serve as *relative measures of the risk of shallow ground water contamination by chemicals used in agriculture.* The 1982 NRI and associated data bases provided the necessary site-specific information on soil properties, crop type, and climate to calculate vulnerability indexes in a consistent manner for all areas of the country.

## Ground Water Vulnerability Index for Pesticides

The Ground Water Vulnerability Index for Pesticides (GWVIP) is a function of soil leaching potential, pesticide leaching potential, precipitation, and chemical use. It represents an extension to the National level of the Soil-Pesticide Interaction Screening Procedure (SPISP). Chemical use at each NRI sample point was inferred on the basis of the crop grown using information on chemical use by crop and by State assembled by Resources For the Future (RFF).

**The GWVIP Algorithm**

Algebraic expressions for the GWVIP and aggregate measures are as follows:

$$\mathrm{GWVIP}_i = \sum_{j=1}^{4} \mathrm{PF}_i \times \mathrm{PESTWT}_{ij} \times \mathrm{LEACH}_{ij}$$

$$\mathrm{TOTAL\ GWVIP} = \sum_{i=1}^{N} \mathrm{EXPAND}_i \times \mathrm{GWVIP}_i$$

$$\mathrm{AVG\ GWVIP} = \frac{\mathrm{TOTAL\ GWVIP}}{\sum_{i=1}^{N} \mathrm{EXPAND}_i}$$

where:

| | |
|---|---|
| $i$ | = 1,2,3, ... N NRI points in a specific geographical area. |
| $j$ | = 1,2,3,4 pesticide leaching classes (large, medium, small, and extra small). |
| $\mathrm{PF}_i$ | = percolation factor calculated for each NRI point. |
| $\mathrm{PESTWT}_{ij}$ | = pesticide-use weights derived from percent acres treated data, calculated for each pesticide leaching class at each NRI point. |
| $\mathrm{LEACHWT}_{ij}$ | = leaching weights reflecting relative amounts of pesticide leaching below the root zone for each pesticide leaching class and at each NRI point. |
| $\mathrm{EXPAND}_i$ | = expansion factor in acres for an NRI point. |
| TOTAL GWVIP | = summation of GWVIP scores for NRI points in a specific geographic area, weighted by the expansion factors. |
| AVG GWVIP | = per acre measure of vulnerability. |

Essentially, the total GWVIP is a weighted sum of acres in a given geographic area, where the "weights" reflect the relative risk for leaching of pesticides below the root zone.

The GWVIP is based on acres treated with pesticides. Application rate information is not used to estimate the GWVIP because it was not designed to reflect the *amount* of chemicals leaching into the ground water.

Because the GWVIP is an extension of a screening procedure, it is designed to minimize the likelihood of incorrectly identifying an area as having a low potential for contamination. The GWVIP is designed to classify an area as having a potential problem even if the likelihood is small. A GWVIP above a predetermined critical level indicates that the area is at risk of ground water contamination from agrichemical use and that further investigation is recommended. Conversely, areas with GWVIP scores below some critical level have very small chance of ground water contamination.

### Soil-pesticide leaching factor

The soil-pesticide leaching factor, LEACHWT, is derived directly from the Soil-Pesticide Interaction Screening Procedure. To aggregate over several NRI sample points with different leaching potentials or to aggregate over several chemicals at a single point, the discrete rankings in the SPISP matrix must be replaced with relative weights. Using statistics from the GLEAMS simulations used to derive the SPISP matrix (see table C–5 in appendix C), relative weights were obtained that represent the approximate maximum proportion of a chemical class that might leach below the root zone. LEACHWT values were assigned to each of the 16 combinations of soil leaching classes and pesticide leaching classes as shown in table 7.

Only a few—less than 1 percent—of the 40,896 GLEAMS combinations registered a higher percent leaching value than that shown in table 7. The values .825 and .619, representing maximum pesticide losses of 82 and 62 percent, respectively, correspond to the *Pesticide Loss Potential 1* in the SPISP matrix. The value .206 corresponds to *Potential 2*, and the values .050, .011, and .002 correspond to *Potential 3*.

**Table 7** LEACHWT values used to calculate the GWVIP

| Soil leaching class | Pesticide leaching class: Large | Medium | Small | Extra small |
|---|---|---|---|---|
| High | .825 | .619 | .206 | .011 |
| Intermediate | .619 | .206 | .050 | 0 |
| Low | .206 | .050 | .002 | 0 |
| Very Low | .011 | .002 | 0 | 0 |

The value 0 corresponds to the lowest potential, which was created to reflect conditions where essentially no pesticide would be expected to leach below the root zone.

Once the soil leaching class for an NRI point has been determined, the appropriate LEACHWT values are obtained from table 7, one for each of the four pesticide leaching classes.

### Pesticide use

PESTWT is derived from pesticide use data on percent acres treated compiled by Resources For the Future. Data represents chemical use practices from about 1987 through 1991. Pesticide use for each NRI point is inferred by relating estimates of pesticide use by State and by crop to the crop type reported for the point in the 1982 NRI.

A separate PESTWT value was determined for each of the four pesticide leaching classes at each NRI sample point. If the pesticide leaching class contained only a single pesticide, PESTWT was set equal to the percent acres treated for that pesticide. If more than one pesticide was assigned to a pesticide leaching class, PESTWT was set equal to the sum of the percent acres treated within the same pesticide leaching class. If a wide array of chemicals were used on a crop, the NRI sample point could have a PESTWT value for each of the four pesticide leaching classes. It is also possible, and even expected, that PESTWT for one or more pesticide leaching classes could exceed 100.

### Percolation factor

The amount of water that percolates through and below the root zone is an important determinant of the amount of pesticides leached. The percolation factor, PF, was developed by modifying the nitrate leaching index of Williams and Kissel (1991) to include an adjustment for irrigation. PF was determined for each NRI sample point using the methods explained previously and in appendix D.

### Expansion factor

The NRI is based on a stratified random sampling design (appendix A). The expansion factor, EXPAND, is the acreage that the NRI point represents, which was determined for each sample point during the development of the NRI sample design. Expansion factors are used to aggregate vulnerability scores over a collection of NRI sample points to obtain a total or average score for a large geographic area.

## Criteria for Identifying Low Risk and High Risk Cropland Areas

Because the GWVIP was derived from a screening procedure, it is possible to develop criteria to identify points that are most likely to be in a high risk group and points that are most likely to be in a low risk group. This was done by extending the principles used to develop the four pesticide loss potentials associated with the SPISP. The criteria apply only to NRI sample points designated as cropland.

The two lowest SPISP pesticide loss potentials, *Potentials 3 and 4*, have a low risk of ground water contamination by pesticides. A LEACHWT of .05 or less is associated with these potentials. A cutoff for the sum of PESTWT*LEACHWT that roughly corresponds to these two potentials is obtained by setting the PESTWT cutoff at 100 (e.g., 100% acres treated) and the LEACHWT cutoff at .05. A low risk-high risk boundary for PF was set at 6 (e.g., 6 inches percolation below the root zone annually). These variable-specific cutoffs translate into a joint low-risk cutoff for the GWVIP of 30 (.05*100*6). NRI sample points with GWVIP values below 30 either have soils that do not leach easily, use pesticides that do not leach easily, or have low percolation factors. Points that have a GWVIP below 30 are not necessarily problem free, but are unlikely to have serious ground water contamination problems associated with normal pesticide use.

Using the same approach, the criterion for NRI sample points that may have a high risk of ground water contamination was determined to be 124. This criterion corresponds roughly to the two highest SPISP pesticide loss potentials. A LEACHWT value of .206 or greater is associated with *Potentials 1 and 2*. Using the same low risk/high risk boundary values for PESTWT and PF as presented in the preceding paragraph, the joint cutoff value of 124 is obtained (.206*100*6). If the GWVIP for an NRI sample point exceeds 124, the sample point either has soils that leach the pesticides in use, or it has very high pesticide use or percolation factor, or both.

A GWVIP value of more than 124 does not necessarily indicate a problem. In fact, the SPISP was derived in a manner that accepts false positives as it minimizes the occurrence of false negatives. Rather, the high-risk cutoff of 124 provides a screening criterion for identifying areas that are the most likely to have ground water contamination now or in the future, assuming farming practices do not change. Further investigation is required to verify the presence of significant pesticide leaching.

This approach leaves a gap in coverage. NRI sample points that have GWVIP scores between 30 and 124 cannot clearly be designated as either low risk or high risk. About 20 percent of the cropland acres nationally are in this "gray" zone.

## Ground Water Vulnerability Index for Nitrogen Fertilizer

A Ground Water Vulnerability Index for Nitrogen fertilizer (GWVIN) was calculated in the same way as the GWVIP except that the two variables related to pesticide leaching—PESTWT and LEACHWT—were replaced by an estimate of excess nitrogen fertilizer applied. The calculation was made as follows:

$$\mathrm{GWVIN}_i = \mathrm{PF}_i \times \mathrm{EXCESSN}_i$$

$$\mathrm{TOTAL\ GWVIN} = \sum_{i=1}^{N} \mathrm{EXPAND}_i \times \mathrm{GWVIN}_i$$

$$\mathrm{AVG\ GWVIN} = \frac{\mathrm{TOTAL\ GWVIN}}{\sum_{i=1}^{N} \mathrm{EXPAND}_i}$$

where $\mathrm{EXCESSN}_i$ is an estimate of excess nitrogen fertilizer applied per acre at each NRI point and the remaining variables are as defined for the GWVIP.

Excess nitrogen per acre is defined to be the difference between the amount of nitrogen fertilizer applied and the amount of nitrogen taken up by the crop and removed from the field (see appendix F). The calculation is made as follows:

$$N_e = N_f - \left(N_g + N_s - N_l\right)$$

where:

$N_e$ = excess nitrogen fertilizer applied.
$N_f$ = amount of commercial nitrogen fertilizer applied.
$N_l$ = nitrogen credit from previous legume crops.
$N_g$ = nitrogen content of harvested portion of crop (i.e., grain).
$N_s$ = nitrogen content of other plant material removed from the field.

All components of the algorithm are estimated in units of pounds of nitrogen per acre. County level estimates of excess nitrogen fertilizer applied for three major crops—corn, wheat, and cotton—were imputed to the 1982 NRI sample points by matching crop type and county.

## Limitations to Use of Vulnerability Indexes

The following caveats are especially important in using the GWVIP and the GWVIN and its aggregates as decision aids:

- Land use data is for 1982, the year for which the most comprehensive land use data was available. Although total cropland acreage has remained fairly stable since the early 1980s, there has been a pronounced shift from harvested cropland to cropland idled in government programs. These changes could alter the spatial distribution of risk factors in some parts of the country.

- The analysis incorporates factors that pertain to leaching of chemicals past the soil zone, and so addresses the potential for contamination of shallow ground water, but does not include factors that impact contamination of deeper ground water.

- No adjustment was made for multiple applications of a chemical, nor was application rate included in the calculation. Not accounting for application rate or multiple applications creates the situation where two sample points may be "scored" the same even though the quantity of chemicals used at one point could be much higher. Because the purpose of the GWVIP is to measure only the potential for contamination, the amount of chemical used is not relevant. The potential for contamination would exist no matter how small the amount of chemical used. The sample point where the higher amount of pesticide was used is, nevertheless, more potentially "hazardous" to society if ground water contamination occurs because the concentration of the chemical in the ground water would be higher.

- This approach also does not account for differences in chemical use among points where the same crop is grown, but different rotation schemes or management practices are used. For example, PESTWT is the same for corn grown as part of a rotation cropping system as for continuous corn operations.

- The excess nitrogen fertilizer applied is based on estimates of crop uptake. The excess is available for leaching, but may also run off, remain stored in the soil and used by the next crop, or may volatilize into the atmosphere. For a highly leaching soil, however, most of the excess is likely to leach into the ground water.

- The GWVIN represents a partial measure of the potential for ground water contamination from agricultural activities because it does not include nitrate sources from farming activities other than corn, cotton, and wheat production.

# Ground Water Vulnerability Varies Geographically

These vulnerability indexes were derived specifically to compare the risk of shallow ground water contamination by chemicals used in agriculture in one area to the risk in another area using a consistent measurement approach. Factors that determine vulnerability differ in virtually every major agricultural region of the country. This study shows that the potential for ground water contamination related to agricultural chemical use is geographically diverse both nationally and regionally.

## Potential for Contamination by Pesticides

The average GWVIP for each polygon in the cartographic data base is shown in figure 10. Values have been normalized to facilitate comparisons with the GWVIN. Each of the five non-zero classes on the map contains an equal number of polygons. Because the averages are based on all NRI sample points, figure 10 reflects the spatial distribution of vulnerability taking into account the mitigating influence of land uses other than cropland. (Recall that noncropland NRI sample points have a zero GWVIP value.)

Highest values (the upper 20 percent of the distribution) occur along the Coastal Plains stretching from Alabama, Florida, and Georgia north to the Chesapeake Bay area; the Corn Belt States (especially Illinois and Indiana); the Mississippi River Valley; and several irrigated areas in the West. A confluence of factors indicates that these areas are more at risk of ground water contamination from pesticide use than are other areas of the country. The highest State average GWVIPs are for Delaware, Florida, Georgia, Maryland, South Carolina, New Jersey, Indiana, North Carolina, Alabama, and Illinois (table 8).

The average GWVIP can also be calculated using only those NRI sample points designated as cropland. This calculation is useful for comparing the intensity of vulnerability among areas of the country. An area with little cropland, but high vulnerability on that cropland, will score high using this calculation, whereas low scores may have been obtained for the same area when the noncropland sample points were taken into account.

State average GWVIPs for *cropland only* are also presented in table 8. The eight highest State averages were for Florida, Delaware, Georgia, Alabama, South Carolina, New Jersey, North Carolina, and Maryland—all States along the Coastal Plain. States that have the lowest average State scores are North Dakota, Montana, South Dakota, Wyoming, Utah, Kansas, and Nevada. These states have the least potential for ground water contamination even though several have significant cropland acreage (North Dakota is 66% cropland).

### Low risk areas

Not all cropland is vulnerable to leaching. The low risk criterion previously developed is a GWVIP less than 30. NRI sample points that meet this criterion are considered to have a negligible chance of ground water contamination from pesticide use. The National distribution of these low risk areas is shown in figure 11.

For all non-Federal rural land, 9.4 percent (128 million acres) is cropland where chemicals are used and has GWVIP scores below 30 (table 9). This constitutes about a fourth of all cropland. Nearly all agricultural States have significant acreage that meets this low risk criterion. States that have a disproportionate amount of land in this low risk group are North Dakota, South Dakota, Texas, and Kansas. Areas of concentration also occur in parts of Louisiana, Arkansas, Mississippi, northern Minnesota, and eastern Washington.

The low risk areas are more pronounced where the percent area calculation is made on the basis of cropland acres only (fig. 12). Over 40 percent of the cropland in Arkansas, Louisiana, Maine, North Dakota, Missouri, West Virginia, Wyoming, Mississippi, Texas, and South Dakota is low risk (table 9). Figure 12 shows that the majority of the cropland acres in the Great Plains States have a negligible ground water contamination risk. Generally less than 20 percent of the cropland in the Midwest and the Atlantic Coastal Plain States, however, is low risk.

A significant area—24 million acres, or 6 percent of the cropland acres nationally—is cropland with no apparent pesticide use (table 9). GWVIP scores for these sample points are zero. The bulk of this is hayland and idle cropland.

## High risk areas

High risk areas are associated with clusters of NRI sample points that have a GWVIP of more than 124. Because it was derived from a screening method, this high risk criterion is less discriminating than the low risk criterion. Further investigation would be expected to show that the actual risk of ground water contamination in some areas is lower than the GWVIP score would suggest.

The National distribution of high risk areas is shown in figure 13. In this figure, the percent area is based on all non-Federal rural land, so the calculation includes noncropland acres. Figure 13 thus highlights areas of the country that have a potential for ground water contamination for the area as a whole. Overall, 10.4 percent of the non-Federal rural land (143 million acres) has GWVIP scores of more than 124 (table 9). Most regions of the country have at least some area that is in this high risk group. States that have the highest proportion of acreage are Illinois, Indiana, Delaware, Iowa, and Ohio. These States contain a third of the high-risk acreage nationally. The Midwest States stand out more than the other vulnerable areas because of the high proportion of cropland (or, conversely, the lower proportion of cropland in areas like the Southeast and the East).

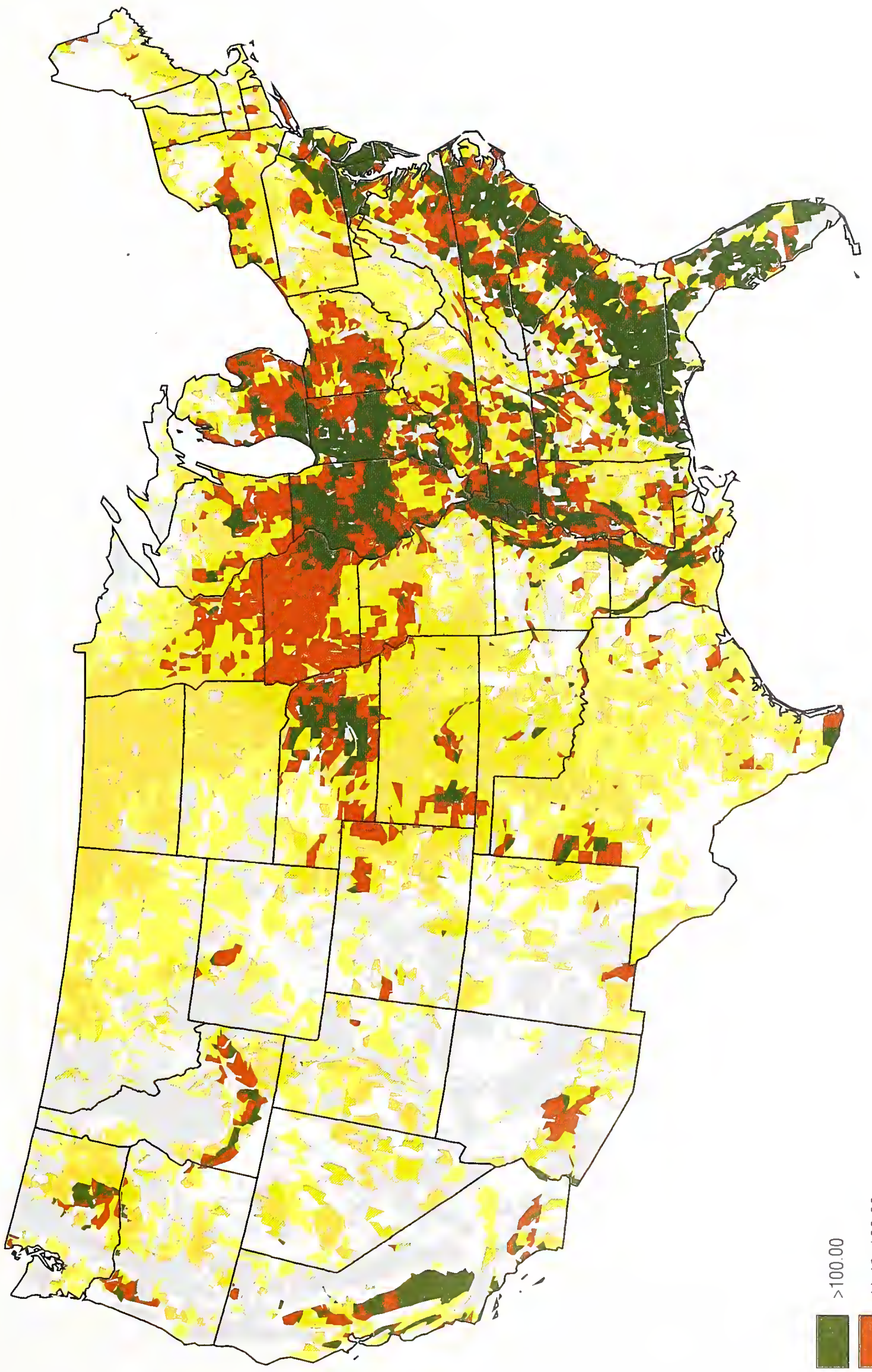
**Table 8** Average scores by State for the Ground Water Vulnerability Index for Pesticides (GWVIP)

| | Average over all non-Federal rural land | | Average over cropland only | | | Average over all non-Federal rural land | | Average over cropland only | |
|---|---|---|---|---|---|---|---|---|---|
| | Average | Rank | Average | Rank | | Average | Rank | Average | Rank |
| Alabama | 267.5 | 9 | 1,742.9 | 4 | Nebraska | 110.7 | 16 | 256.6 | 22 |
| Arizona | 13.1 | 38 | 423.7 | 15 | Nevada | 7.0 | 44 | 82.4 | 42 |
| Arkansas | 81.0 | 21 | 286.3 | 19 | New Hampshire | 4.3 | 48 | 124.0 | 35 |
| California | 81.0 | 20 | 377.2 | 16 | New Jersey | 298.0 | 6 | 1,200.8 | 6 |
| Colorado | 26.4 | 32 | 102.6 | 38 | New Mexico | 5.8 | 46 | 117.6 | 36 |
| Connecticut | 35.7 | 29 | 337.6 | 18 | New York | 50.6 | 25 | 232.2 | 23 |
| Delaware | 1,044.7 | 1 | 2,058.3 | 2 | North Carolina | 267.9 | 8 | 1,047.8 | 7 |
| Florida | 435.8 | 2 | 3,328.7 | 1 | North Dakota | 14.9 | 37 | 22.6 | 48 |
| Georgia | 359.6 | 3 | 1,767.4 | 3 | Ohio | 106.4 | 19 | 192.9 | 27 |
| Idaho | 44.5 | 28 | 131.6 | 34 | Oklahoma | 28.1 | 31 | 96.1 | 39 |
| Illinois | 211.3 | 10 | 272.5 | 21 | Oregon | 23.4 | 34 | 154.5 | 31 |
| Indiana | 288.2 | 7 | 424.6 | 14 | Pennsylvania | 67.0 | 24 | 282.9 | 20 |
| Iowa | 128.6 | 14 | 163.6 | 30 | Rhode Island | 8.2 | 43 | 150.1 | 32 |
| Kansas | 47.8 | 26 | 81.0 | 43 | South Carolina | 304.3 | 5 | 1,414.2 | 5 |
| Kentucky | 112.0 | 15 | 427.3 | 13 | South Dakota | 10.7 | 40 | 28.0 | 46 |
| Louisiana | 108.7 | 17 | 430.0 | 12 | Tennessee | 154.3 | 11 | 632.7 | 10 |
| Maine | 8.6 | 42 | 171.5 | 29 | Texas | 18.7 | 35 | 88.2 | 41 |
| Maryland | 351.9 | 4 | 999.5 | 8 | Utah | 10.1 | 41 | 79.4 | 44 |
| Massachusetts | 17.2 | 36 | 224.9 | 24 | Vermont | 25.1 | 33 | 205.3 | 25 |
| Michigan | 107.4 | 18 | 340.4 | 17 | Virginia | 130.9 | 13 | 828.9 | 9 |
| Minnesota | 47.1 | 27 | 91.2 | 40 | Washington | 29.8 | 30 | 107.3 | 37 |
| Mississippi | 145.0 | 12 | 528.0 | 11 | West Virginia | 11.4 | 39 | 141.6 | 33 |
| Missouri | 68.8 | 23 | 180.1 | 28 | Wisconsin | 74.5 | 22 | 197.8 | 26 |
| Montana | 6.1 | 45 | 23.0 | 47 | Wyoming | 4.9 | 47 | 60.6 | 45 |
| | | | | | **All 48 States** | 86.2 | | 285.8 | |

**Table 9** Distribution of acres with a high risk of ground water contamination by pesticides (GWVIP > 124) and acres with a low risk (GWVIP < 30)

| | GWVIP > 124 | | | GWVIP between 0 and 30 | | | GWVIP = 0 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Million acres | Percent of non-Federal rural land | Percent of cropland alone | Million acres | Percent of non-Federal rural land | Percent of cropland alone | Million acres | Percent of non-Federal rural land | Percent of cropland alone |
| Alabama | 3.282 | 11.3 | 73.3 | 0.543 | 1.9 | 12.1 | 0.038 | 0.1 | 0.9 |
| Arizona | 0.797 | 2.0 | 66.1 | 0.065 | 0.2 | 5.4 | 0.012 | 0.0 | 1.0 |
| Arkansas | 2.534 | 9.0 | 31.9 | 4.574 | 16.4 | 57.6 | 0.138 | 0.5 | 1.7 |
| California | 4.394 | 9.2 | 42.8 | 2.640 | 5.5 | 25.7 | 0.252 | 0.5 | 2.5 |
| Colorado | 1.723 | 4.4 | 17.1 | 1.395 | 3.6 | 13.9 | 0.047 | 0.1 | 0.5 |
| Connecticut | 0.088 | 3.8 | 36.0 | 0.002 | 0.1 | 0.9 | 0.000 | 0.0 | 0.0 |
| Delaware | 0.489 | 48.2 | 95.0 | 0.000 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 |
| Florida | 2.203 | 8.2 | 62.8 | 0.043 | 0.2 | 1.2 | 0.003 | 0.0 | 0.1 |
| Georgia | 5.807 | 18.1 | 88.8 | 0.174 | 0.5 | 2.7 | 0.010 | 0.0 | 0.1 |
| Idaho | 1.807 | 9.8 | 29.0 | 1.229 | 6.7 | 19.7 | 0.180 | 1.0 | 2.9 |
| Illinois | 17.732 | 56.0 | 72.3 | 3.266 | 10.3 | 13.3 | 0.135 | 0.4 | 0.6 |
| Indiana | 10.149 | 50.6 | 74.6 | 1.688 | 8.4 | 12.4 | 0.123 | 0.6 | 0.9 |
| Iowa | 11.509 | 34.5 | 43.9 | 3.589 | 10.8 | 13.7 | 0.172 | 0.5 | 0.7 |
| Kansas | 4.877 | 9.9 | 16.9 | 9.398 | 19.2 | 32.5 | 1.696 | 3.5 | 5.9 |
| Kentucky | 3.628 | 16.1 | 61.5 | 1.620 | 7.2 | 27.5 | 0.058 | 0.3 | 1.0 |
| Louisiana | 2.151 | 8.8 | 34.6 | 3.081 | 12.5 | 49.6 | 0.002 | 0.0 | 0.0 |
| Maine | 0.309 | 1.6 | 32.4 | 0.132 | 0.7 | 13.9 | 0.352 | 1.9 | 37.0 |
| Maryland | 1.446 | 28.5 | 80.9 | 0.119 | 2.3 | 6.7 | 0.013 | 0.3 | 0.7 |
| Massachusetts | 0.074 | 2.0 | 26.0 | 0.017 | 0.5 | 5.9 | 0.001 | 0.0 | 0.4 |
| Michigan | 4.253 | 14.3 | 45.4 | 0.994 | 3.4 | 10.6 | 0.058 | 0.2 | 0.6 |
| Minnesota | 4.840 | 11.0 | 21.2 | 6.185 | 14.0 | 27.1 | 1.499 | 3.4 | 6.6 |
| Mississippi | 3.318 | 12.4 | 45.2 | 3.299 | 12.3 | 44.9 | 0.008 | 0.0 | 0.1 |
| Missouri | 4.595 | 11.9 | 31.1 | 5.362 | 13.8 | 36.3 | 1.015 | 2.6 | 6.9 |
| Montana | 0.451 | 0.7 | 2.6 | 4.478 | 7.0 | 26.2 | 0.860 | 1.3 | 5.0 |
| Nebraska | 9.170 | 19.7 | 45.6 | 5.253 | 11.3 | 26.1 | 0.806 | 1.7 | 4.0 |
| Nevada | 0.205 | 2.1 | 25.1 | 0.036 | 0.4 | 4.4 | 0.008 | 0.1 | 1.0 |
| New Hampshire | 0.032 | 0.7 | 20.2 | 0.002 | 0.0 | 1.0 | 0.000 | 0.0 | 0.0 |
| New Jersey | 0.572 | 17.7 | 71.5 | 0.008 | 0.2 | 1.0 | 0.000 | 0.0 | 0.0 |
| New Mexico | 0.519 | 1.1 | 22.2 | 0.227 | 0.5 | 9.7 | 0.293 | 0.6 | 12.5 |
| New York | 1.616 | 6.1 | 27.9 | 0.671 | 2.5 | 11.6 | 0.070 | 0.3 | 1.2 |
| North Carolina | 5.159 | 19.8 | 77.4 | 0.708 | 2.7 | 10.6 | 0.008 | 0.0 | 0.1 |
| North Dakota | 0.255 | 0.6 | 1.0 | 9.260 | 22.8 | 34.5 | 4.689 | 11.5 | 17.5 |
| Ohio | 6.818 | 30.9 | 56.0 | 2.768 | 12.5 | 22.8 | 1.399 | 6.3 | 11.5 |
| Oklahoma | 2.106 | 5.5 | 19.0 | 2.415 | 6.4 | 21.7 | 1.362 | 3.6 | 12.3 |
| Oregon | 0.876 | 3.3 | 21.8 | 0.803 | 3.0 | 20.0 | 0.045 | 0.2 | 1.1 |
| Pennsylvania | 2.455 | 10.0 | 42.0 | 0.298 | 1.2 | 5.1 | 0.009 | 0.0 | 0.2 |
| Rhode Island | 0.008 | 1.5 | 27.6 | 0.009 | 1.8 | 32.7 | 0.001 | 0.1 | 1.8 |
| South Carolina | 2.854 | 17.5 | 81.2 | 0.238 | 1.5 | 6.8 | 0.000 | 0.0 | 0.0 |
| South Dakota | 0.331 | 0.8 | 2.0 | 6.951 | 15.9 | 41.4 | 2.901 | 6.6 | 17.3 |
| Tennessee | 3.492 | 15.3 | 62.7 | 1.194 | 5.2 | 21.4 | 0.067 | 0.3 | 1.2 |
| Texas | 6.366 | 4.1 | 19.5 | 14.427 | 9.4 | 44.1 | 4.651 | 3.0 | 14.2 |
| Utah | 0.300 | 1.9 | 14.8 | 0.486 | 3.0 | 23.9 | 0.094 | 0.6 | 4.6 |
| Vermont | 0.246 | 4.7 | 38.0 | 0.171 | 3.2 | 26.4 | 0.050 | 0.9 | 7.6 |
| Virginia | 2.128 | 10.4 | 65.9 | 0.357 | 1.7 | 11.1 | 0.021 | 0.1 | 0.7 |
| Washington | 1.186 | 4.3 | 15.4 | 1.787 | 6.5 | 23.3 | 0.122 | 0.4 | 1.6 |
| West Virginia | 0.190 | 1.4 | 17.5 | 0.425 | 3.1 | 39.1 | 0.100 | 0.7 | 9.2 |
| Wisconsin | 3.540 | 11.8 | 31.3 | 1.289 | 4.3 | 11.4 | 0.055 | 0.2 | 0.5 |
| Wyoming | 0.254 | 0.8 | 9.9 | 0.879 | 2.8 | 34.2 | 0.278 | 0.9 | 10.8 |
| **48 State Total** | 143.130 | 10.4 | 34.5 | 104.552 | 7.6 | 25.2 | 23.696 | 1.7 | 5.7 |

**Figure 10** Normalized average Ground Water Vulnerability Index for Pesticides



>100.00
41.48–100.00
15.12–41.48
3.79–15.12
0.10–3.79
No pesticides used
Non-mapping

**Note**: Average scores were normalized by dividing by the value of the 80th percentile.

U.S. Department of Agriculture, Soil Conservation Service
National Center for Resource Innovations

**Figure 11** Percentage of non-Federal rural land that is cropland **and** has Ground Water Vulnerability Index for Pesticides of < 30

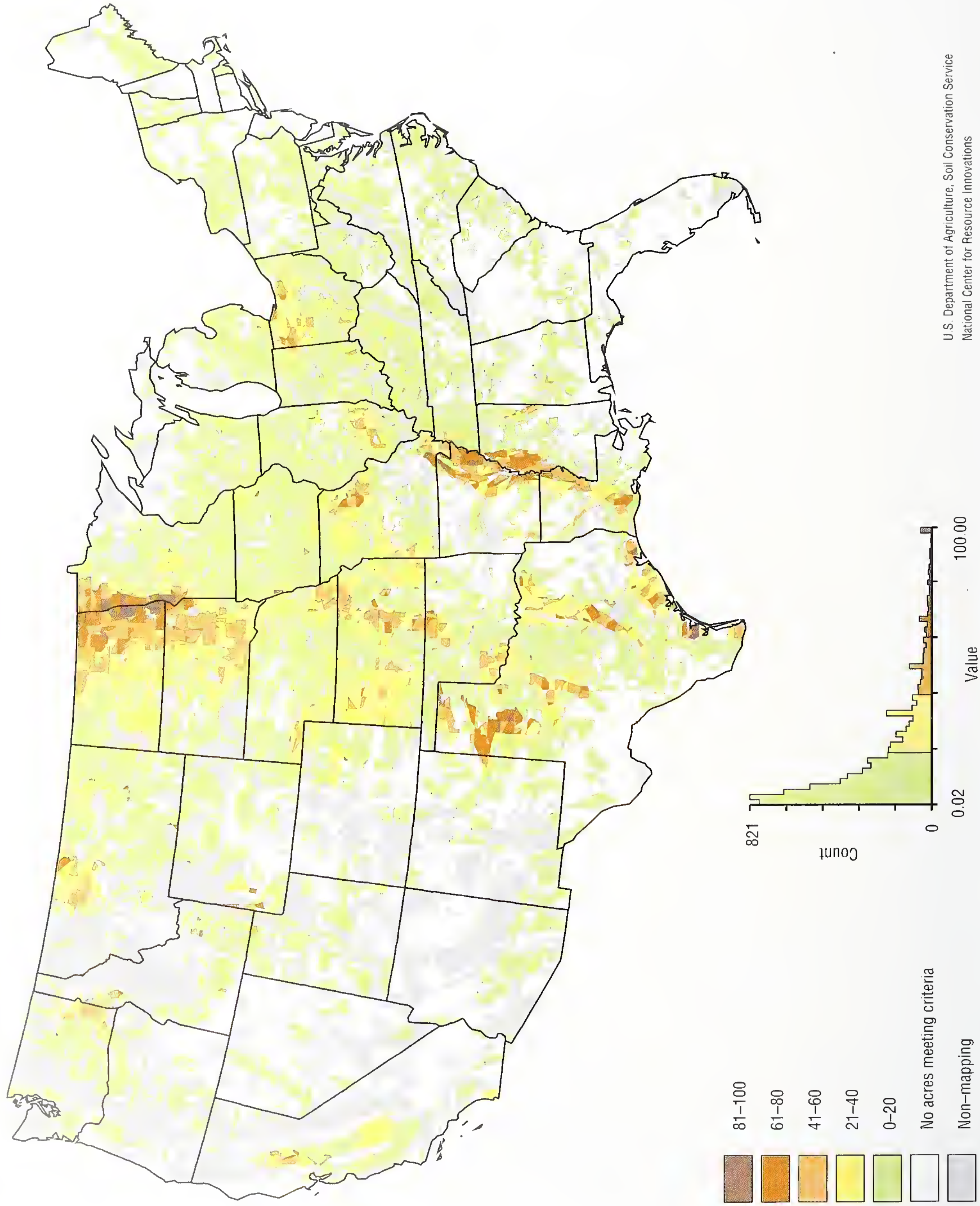


**Figure 12** Percentage of *cropland* area that has Ground Water Vulnerability Index for Pesticides of < 30

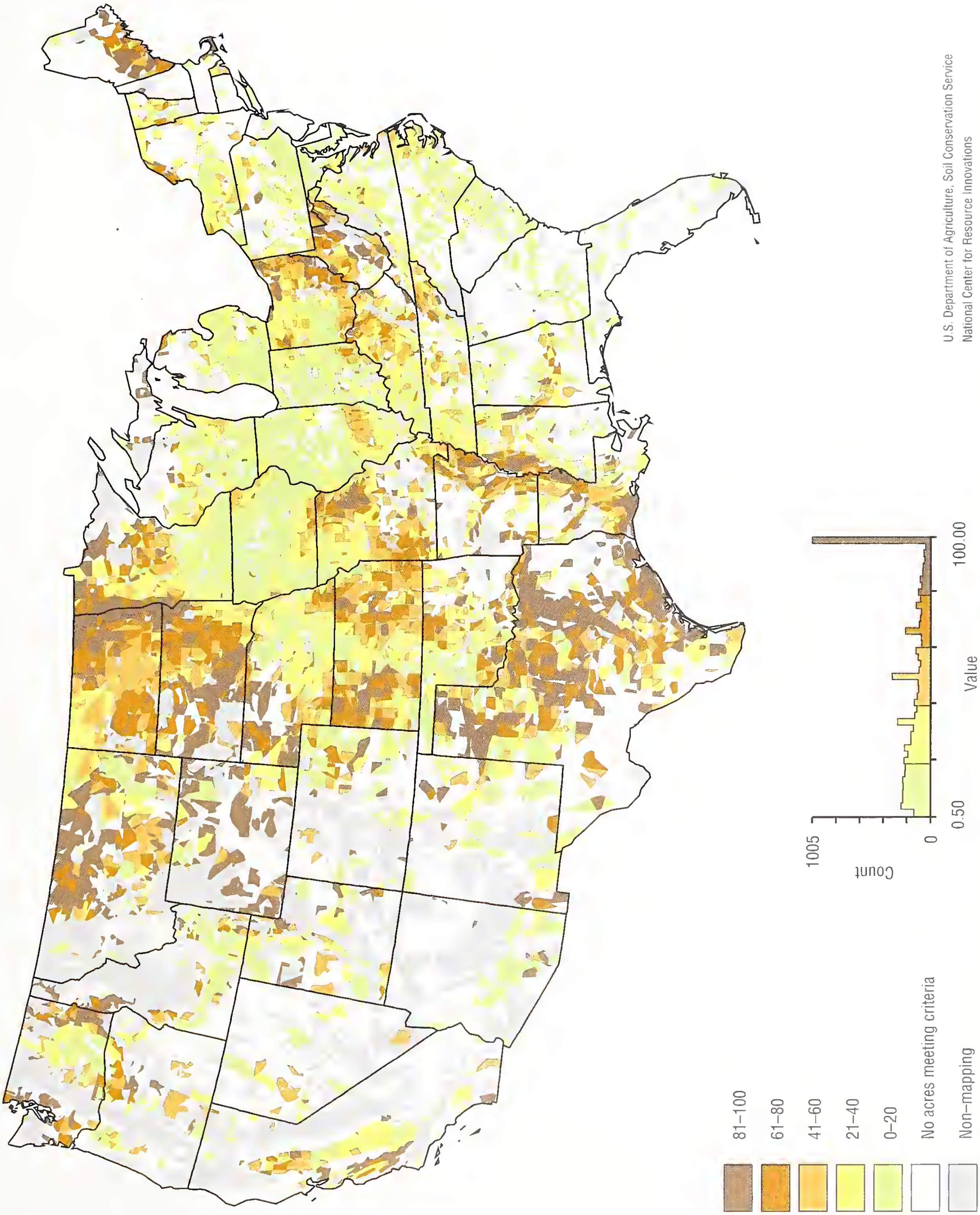



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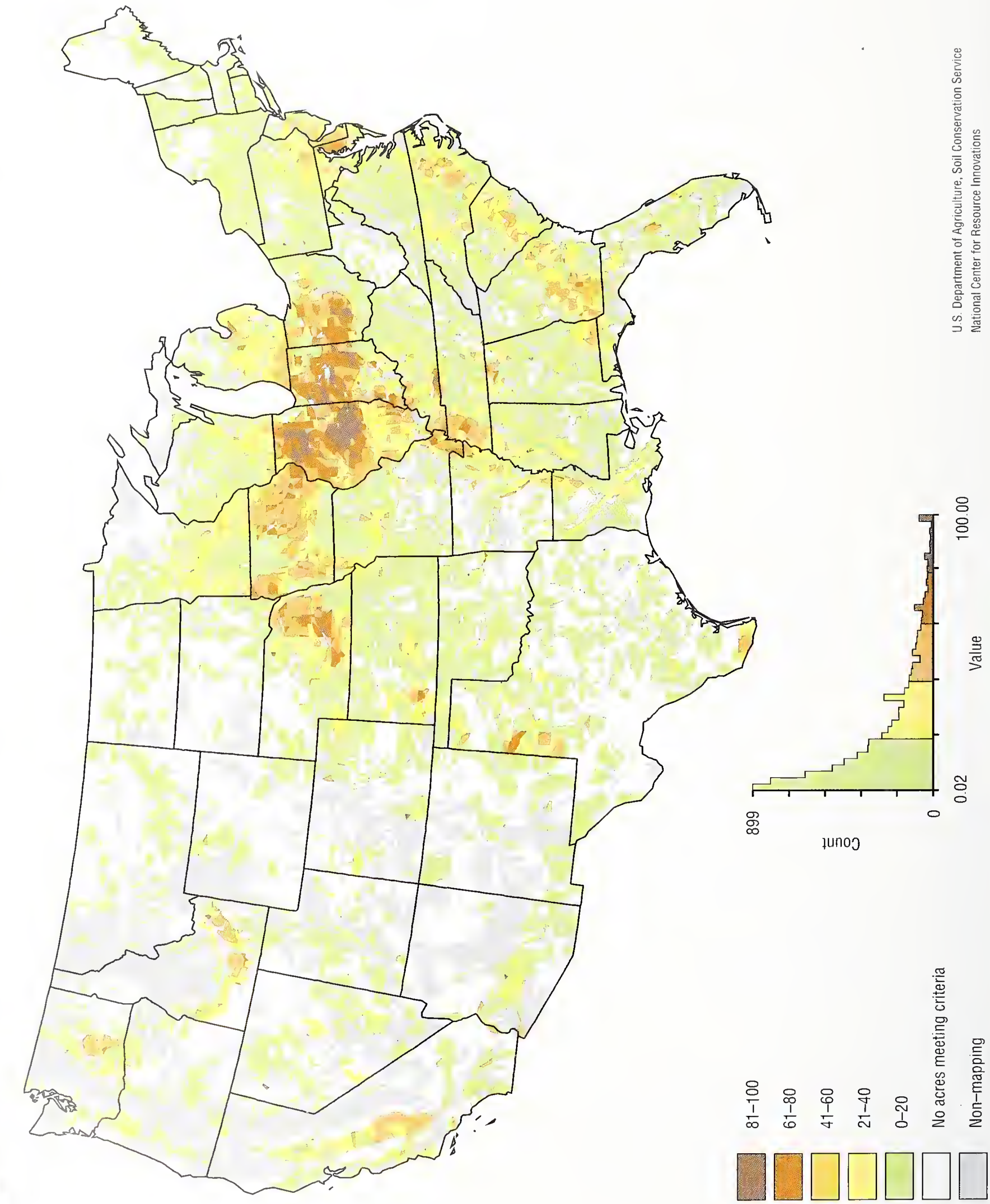
**Figure 13** Percentage of non-Federal rural land that has Ground Water Vulnerability Index for Pesticides of >124



Comparing figure 11 to figure 13 reveals that many areas of the country identified as being in a high risk group also have significant acreage that appears not to be at risk. This is especially apparent for the Mississippi River Valley in the South. This mix of relative vulnerability has important policy implications.

Figure 14 shows the national distribution of these high risk areas calculated on the basis of cropland points only. That is, the percent area calculation is the percentage of *cropland* area that meets the high risk criterion. This figure thus illustrates the national distribution of the potential for ground water contamination for cropland, but does not reflect how widespread the condition is within the area.

Results shown in figure 14 dramatically reinforce conclusions drawn from the previous figures that agricultural activities associated with the highest potential for ground water contamination are most concentrated along the Coastal Plain in the Southeast stretching from Alabama and Florida to eastern Pennsylvania, New Jersey, and southern New York. Over 70 percent of the cropland in Delaware, Georgia, South Carolina, Maryland, North Carolina, Indiana, Illinois, Alabama, and New Jersey meet the high risk criterion (table 9). In contrast, less than 3 percent of the cropland in Montana, North Dakota, and South Dakota is in the high risk group.

This analysis clearly shows that the agricultural areas of the country that have the highest priority for further study and program implementation are in the Midwest and the Coastal Plain in the South and East.

## Potential for Contamination by Nitrogen Fertilizer

High GWVIN scores are distributed generally in the same areas as those that have high GWVIP scores (fig. 15). However, highest GWVIN scores are more predominant in the Corn Belt States—Indiana, Illinois, Iowa, and Ohio have the highest average state scores (table 10). In contrast, the highest GWVIP scores occurred in the Atlantic Coastal Plain States. The most vulnerable areas in the West were predominantly irrigated cropland.

In a similar study using 1990 crop data, Huang et al. (1991) also found that the Corn Belt States have the most acreage of cropland potentially vulnerable to leaching of nitrogen fertilizer. On a per acre basis by crop, however, they reported that the most vulnerable corn acres were in the Mountain States, the most vulnerable acres for wheat were in the Delta States, and the most vulnerable acres for cotton were in Arizona.

The least vulnerable areas are generally in the West and the Great Plains. State average GWVIN scores for cropland acres only were lowest for Nevada, North Dakota, Montana, South Dakota, Wyoming, Colorado, Utah, Idaho, Washington, and Kansas (table 10). *Seven of these states also had the lowest state average GWVIPs for cropland acres.*

## Coincidence Between Population Centers and Vulnerable Areas

Juxtaposing high risk areas and population centers reveals areas where the potential for ground water contamination by chemical use in agriculture is of most concern to society in general. Whether or not a vulnerable area represents a "water quality problem" to society depends not only on the potential for ground water contamination, but also on the demand for water quality (see appendix G). The demand related to ground water is caused by the demand for safe drinking water and for use of lakes, rivers, streams, and estuaries receiving significant discharge flows from ground water sources. Areas of highest water quality demand are likely to be proximate to population centers.

Metropolitan Statistical Areas (MSA) are large population centers together with adjacent communities that have a high degree of social and economic integration with that population center. An MSA contains a city of at least 50,000 population or a Census Bureau defined urbanized area of at least 100,000 (75,000 in New England) (US DOC 1984). MSAs are presented in figure 16.

Correspondence between high risk areas and population centers occur principally along the West and East coasts. The most striking matches occur in California, Florida, the East Coast area stretching from northern Virginia to Rhode Island, and the northern edge of the central Midwest (Indiana, Illinois, and Michigan). Ground water quality "problems" are most likely to be of public concern in these areas.

Other high risk areas defined previously may not be associated with significant demand for water quality. For example, much of the Coastal Plain south of Virginia where the GWVIP scores were quite high has only a few major population centers that coincide with high risk areas.

**Table 10** Average scores by State for the Ground Water Vulnerability Index for Nitrogen fertilizer (GWVIN)

| | Averge over all non-Federal rural land | | Average over cropland only | | | Averge over all non-Federal rural land | | Average over cropland only | |
|---|---|---|---|---|---|---|---|---|---|
| | Average | Rank | Average | Rank | | Average | Rank | Average | Rank |
| Alabama | 49.6 | 15 | 322.8 | 4 | Nebraska | 40.8 | 16 | 94.6 | 28 |
| Arizona | 7.4 | 36 | 238.0 | 10 | Nevada | 0.0 | 48 | 0.0 | 48 |
| Arkansas | 52.3 | 14 | 184.8 | 12 | New Hampshire | 5.0 | 40 | 143.0 | 19 |
| California | 14.7 | 29 | 68.2 | 31 | New Jersey | 39.9 | 17 | 160.7 | 16 |
| Colorado | 5.1 | 38 | 20.0 | 43 | New Mexico | 1.9 | 46 | 39.4 | 38 |
| Connecticut | 29.8 | 20 | 282.3 | 7 | New York | 21.8 | 26 | 99.9 | 27 |
| Delaware | 59.6 | 10 | 117.5 | 24 | North Carolina | 80.6 | 7 | 315.3 | 5 |
| Florida | 18.5 | 27 | 141.2 | 20 | North Dakota | 3.9 | 41 | 5.9 | 47 |
| Georgia | 73.5 | 8 | 361.0 | 2 | Ohio | 92.6 | 4 | 168.0 | 15 |
| Idaho | 11.5 | 32 | 33.9 | 41 | Oklahoma | 18.0 | 28 | 61.6 | 33 |
| Illinois | 197.8 | 2 | 255.1 | 8 | Oregon | 8.6 | 35 | 57.1 | 35 |
| Indiana | 206.7 | 1 | 304.6 | 6 | Pennsylvania | 31.1 | 19 | 131.2 | 21 |
| Iowa | 93.9 | 3 | 119.4 | 23 | Rhode Island | 6.7 | 37 | 123.1 | 22 |
| Kansas | 22.0 | 25 | 37.3 | 39 | South Carolina | 53.1 | 13 | 246.6 | 9 |
| Kentucky | 85.2 | 6 | 325.0 | 3 | South Dakota | 3.8 | 42 | 10.1 | 45 |
| Louisiana | 28.8 | 22 | 114.0 | 25 | Tennessee | 88.1 | 5 | 361.4 | 1 |
| Maine | 2.5 | 44 | 50.0 | 36 | Texas | 12.6 | 31 | 59.6 | 34 |
| Maryland | 62.6 | 9 | 177.7 | 13 | Utah | 3.1 | 43 | 24.2 | 42 |
| Massachusetts | 13.1 | 30 | 171.3 | 14 | Vermont | 9.9 | 33 | 80.7 | 29 |
| Michigan | 32.4 | 18 | 102.6 | 26 | Virginia | 25.3 | 23 | 159.9 | 17 |
| Minnesota | 24.9 | 24 | 48.1 | 37 | Washington | 9.4 | 34 | 34.0 | 40 |
| Mississippi | 56.8 | 11 | 207.0 | 11 | West Virginia | 5.1 | 39 | 63.4 | 32 |
| Missouri | 55.6 | 12 | 145.6 | 18 | Wisconsin | 29.3 | 21 | 77.8 | 30 |
| Montana | 2.2 | 45 | 8.1 | 46 | Wyoming | 1.4 | 47 | 17.4 | 44 |
| | | | | | **All 48 States** | 33.8 | | 111.9 | |

**Figure 14** Percentage of *cropland* area that has Ground Water Vulnerability Index for Pesticides of >124

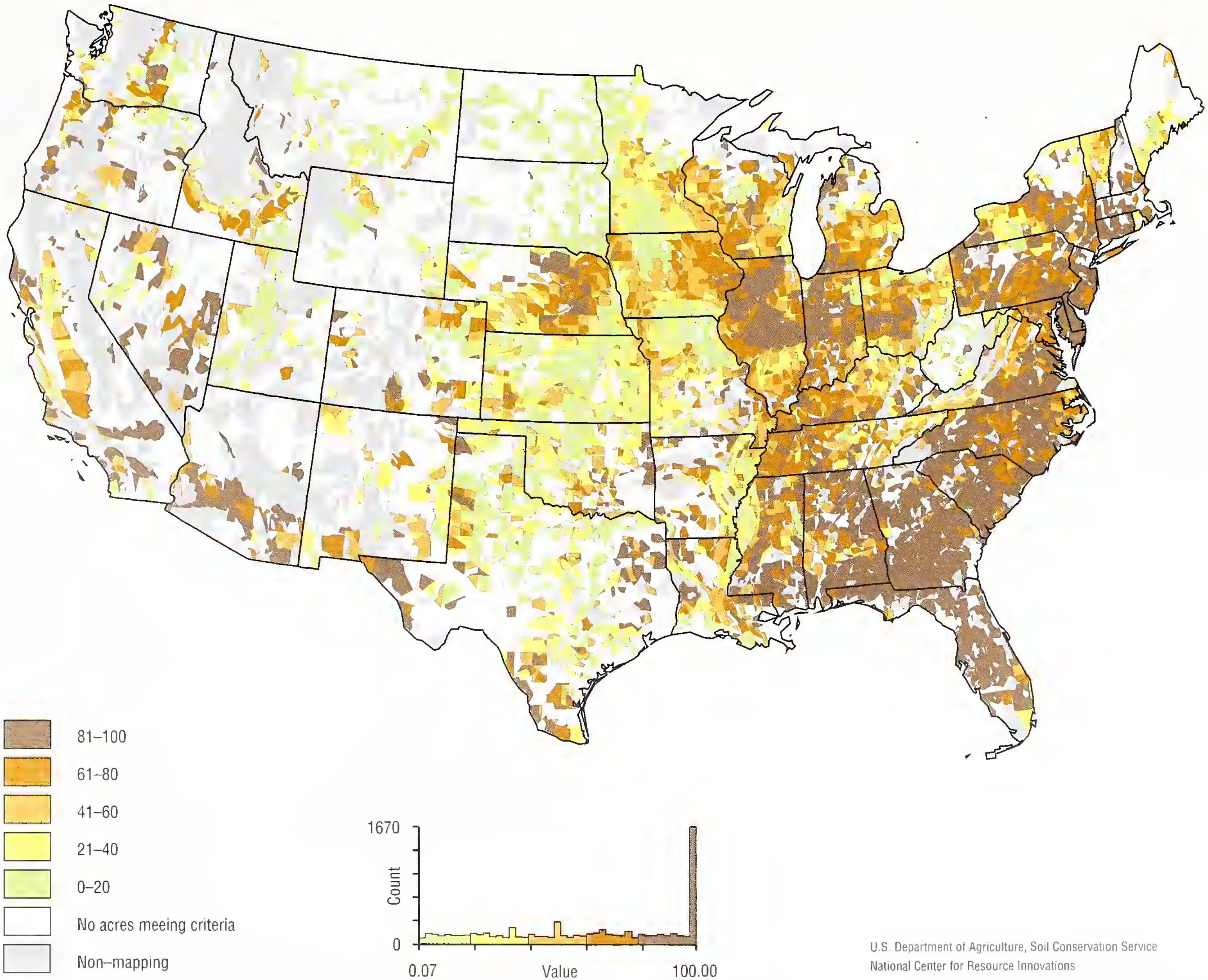
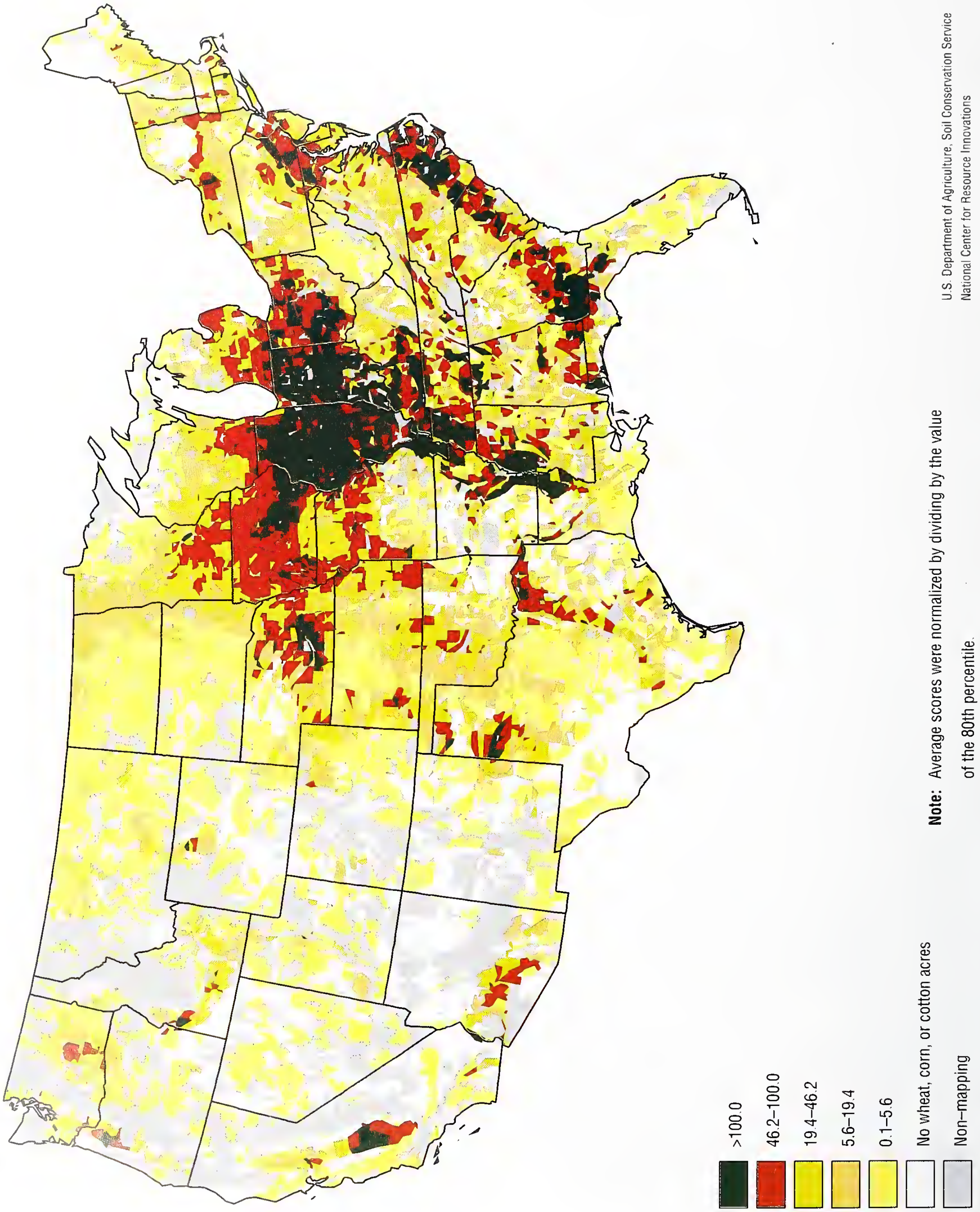


**Figure 15** Normalized average Ground Water Vulnerability Index for Nitrogen fertilizer




**Note:** Average scores were normalized by dividing by the value of the 80th percentile.

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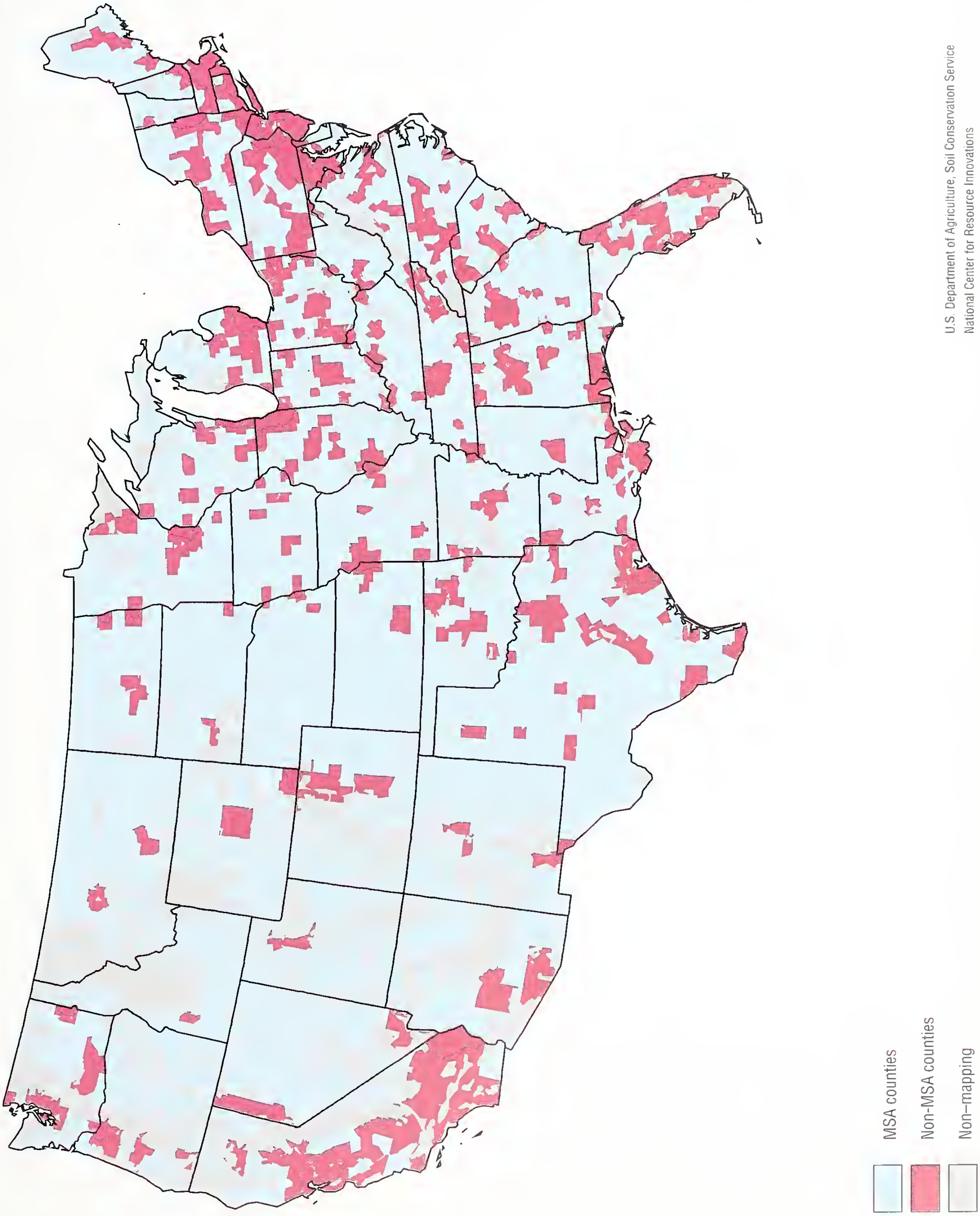
**Figure 16** 1985 Standard Metropolitan Statistical Areas

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# Recommendations for Research

The purpose of this study was to assess the potential for ground water contamination on the basis of information readily available as of mid-1992. As more information becomes available from USDA Water Quality Initiative activities and other water quality research, the analytical framework can be strengthened. What we know, and what we do not know, about agriculture's role in the ground water quality problem needs to be continually reassessed as new research findings are released.

Opportunities for research to contribute to future assessments include:

- An important "gap" in research presently is the lack of information and analysis for specific geographic areas. The problem is not only complex, but it does not occur everywhere. This analysis clearly shows that an important role for government is to provide information and technical assistance to producers and to regional and local government officials.

- More information is needed about the sources of contamination of the agrichemicals found in the ground water. It is important from a policy standpoint to know whether the contamination resulted from the leaching process, or if it was the result of a spill or careless disposal.

- Research is needed to develop new chemicals that are effective against pests and have a low probability of leaching. These new chemical products should be tailored to soil and climate characteristics of high risk areas so that their use will not pose a threat to ground water quality in those regions.

- Knowledge and understanding of the physical process dictating the fate of chemicals applied to crops and transport in soil and water systems are lacking. For example, the information is insufficient on the effects of pH, organic matter, temperature, and microbial activity on persistence. Once agricultural chemicals have reached ground water, we do not know the ability of ecosystems to cleanse themselves or how long such processes might take. Even if chemical applications to cropland were stopped, existing pesticides and nitrates may leach into ground water for long periods of time.

- Our knowledge of the risks posed to humans from exposure to agricultural chemicals at the levels found in ground water is deficient. Research in this area would have a strong impact on the demand for water quality by society.

- More research is needed on the socioeconomic impacts of government policies aimed at controlling ground water pollution from agricultural sources. Perhaps the biggest knowledge gap is the lack of adequate models predicting producer behavior. To determine how a given policy will affect chemical use, it is first necessary to predict what input and output substitutions the agricultural firm is most likely to make, as well as whether or not the firm will participate in government commodity programs.

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# Appendix A: Description of the National Resources Inventory

**J. Jeffery Goebel**
Soil Conservation Service

The National Resources Inventory (NRI) is a multiresource inventory conducted at 5-year intervals by the U.S. Department of Agriculture's Soil Conservation Service (SCS). NRI's serve as the Federal Government's principal source of information on the status, condition, and trends of soil, water, and related resources for the Nation's non-Federal lands.[1]

The data bases developed by this inventory program are unique, provide nationally consistent data, and permit analysis of resource issues in relation to the capability of the land and in terms of soil resources and conditions. Data items include soils, land cover, land use, cropping history, conservation practices, conservation treatment needs, potential cropland, prime farmland, highly erodible cropland, water and wind erosion, wetlands, wildlife habitat, vegetative cover conditions, irrigation, and flood susceptibility. Linkage between NRI and soils data bases allows numerous soil characteristics and interpretations to be treated as additional attributes. Linkages with other data bases are being established, which will greatly enhance assessment of resource conditions in the future.

## Overview of the NRI

### Historical background

For over 50 years SCS has conducted periodic inventories of the Nation's soil, water, and related resources. The earliest efforts were reconnaissance studies—the Soil Erosion Inventory of 1934 and the 1945 Soil and Water Conservation Needs Inventory. The Soil and Water Conservation Needs Inventories of 1958 and 1967 were the agency's first efforts to collect data nationally for scientifically selected sample sites.

The Potential Cropland Study of 1975 and the National Resources Inventories of 1977, 1982, and 1987 were extensions and modifications of the earlier inventories. A 1992 NRI is presently underway.

The first National Inventory of Soil and Water Conservation Needs, commonly called the Conservation Needs Inventory (CNI), was conducted in 1958 under a directive from Ezra T. Benson, then Secretary of Agriculture. The major goal was to accurately determine the conservation treatment needs of the U.S. cropland base. Principal data items in the 1958 inventory were agricultural capability class of the soil and land use. The inventory was based on a stratified random area sample containing about 2 percent of the non-Federal land in the United States. The sampling units were square segments of land ranging from 40 to 640 acres. A map was constructed for each sample segment showing agricultural capability subclasses and land uses for all non-Federal rural land in the segment. Acreage measurements from these maps constituted the primary data source for the 1958 CNI.

In 1967 a second CNI was carried out with the primary purpose of updating the 1958 data. To reduce field costs, the method of data collection was changed from that used in 1958. Instead of mapping the entire segment, data were recorded for a sample of points randomly located within the segment. About 36 points were observed in a typical 160-acre segment.

In 1975 a third nationwide study, the Potential Cropland Study, was carried out. Data were collected on a subsample of the 1967 CNI sample sites. Primary data items were land use, agricultural capability of the soil, potential for converting land not being used for crops to cropland, reasons why certain noncropland would not be converted to cropland, and the amount of prime farmland.

In response to continued demands for additional data on items related to soil and water resources, an NRI was carried out in 1977. In addition to data of the type collected in the previous studies, data on water (sheet and rill) and wind erosion, conservation practices,

[1] The Rural Development Act of 1972 authorizes the resources inventory program within SCS. It directs the Secretary of Agriculture to carry out a land inventory and monitoring program and to issue a report that reflects soil, water, and related resource conditions at not less than 5-year intervals. In addition, the Soil and Water Resources Conservation Act of 1977 and the Food Security Act of 1985 stipulate that the NRI appraisals be the basis for developing a soil and water conservation program, thereby authorizing the National Conservation Program.

incidence of wetlands, and flooding propensity were gathered. This inventory used a subsample of the areas selected for the 1958 CNI. Some of the data items were collected with respect to the entire sample segment; other items were collected with respect to specific points within the sample segment. The 1977 point locations were not the same as the 1967 CNI sample points, and only three points were observed in a typical segment. A second phase of the 1977 NRI was conducted in 1978 and 1979 under the direction of SCS sedimentation geologists and engineers. Data were collected on erosion of streambanks, gullies, construction areas, roads, and roadsides.

The 1982 NRI represented a continuation and an expansion of the 1958, 1967, 1975, and 1977 investigations. Most data items collected in 1977 were collected again in 1982 for the specific purpose of providing estimates of change. More extensive data were collected on soils, irrigation practices, and wetlands. Additional data were collected on critical eroding areas, windbreaks, riparian vegetation, wildlife habitat, and vegetative cover. Consequently, the 1982 NRI was much more comprehensive than were the previous inventories.

The 1987 NRI was designed to establish a data base that would allow natural resource issues to be analyzed at a State level and to allow detection of significant changes between 1982 and 1987 at a regional level. To meet these goals and to conduct the data collection as efficiently as possible, the 1987 NRI involved collecting data for sample locations that had been part of the 1982 NRI.

### Uses of inventory data

NRI data serve a wide range of purposes:

- Monitoring trends in status and condition of resources.
- Helping formulate State and National policy (legislation) on resource concerns, such as conservation reserve, sodbusting, swampbusting, and effects of erosion on agricultural productivity.
- Appraising progress of conservation programs from National, State, and local perspectives.
- Providing information to agency management for allocating resources, funds, and setting proper staffing levels.
- Aiding in research and modeling efforts.

NRI data were used to help formulate and analyze impacts of various provisions of the 1985 Food Security Act. For example, it was used to assess the geographical dispersion of land potentially eligible for the CRP and to allow analysis of regional economic impacts. NRI data have been used to assess the impact of conservation programs on rangeland condition and to evaluate brush invasion problems on rangeland.

The data have also been used to model soil productivity and the off-site effects of erosion. Scientists and engineers have used NRI data to develop and evaluate better erosion prediction models. Acid deposition and biomass production have been analyzed with the help of NRI and related soils data.

The Tennessee Valley Authority uses NRI data to analyze regional resource concerns. States routinely use NRI data to determine the magnitude and location of soil and water resource problems and to develop agency staffing plans to address them.

Many special uses have also been made. For example, a 1984 informational campaign in Missouri based upon NRI data helped pass a 0.1 percent sales tax to support soil and water conservation and state parks. In 1988 the tax was extended for 10 more years.

## The 1982 Inventory

In this publication, Kellogg, Maizel, and Goss used the 1982 Inventory as the basis for assessing the potential for ground water leaching of agrichemicals at the national level. Important details of data collection and sample design for the 1982 NRI are presented here as documentation for the analytical framework used.

### Methods

The primary objective of the 1982 NRI was to establish a data base that would allow analysis of natural resource issues at substate (multicounty) and regional levels, such as Major Land Resource Areas (MLRAs), SCS Administrative Areas, sub-river basins, and Water Resources Council aggregated subareas. Other goals included having basic statistics reconcilable with figures used by other agencies, figures compatible with SCS definitions, data that reflect the base year conditions, and data that are of high quality.

The data base was developed from data collected at three levels:

1) the county,
2) the first-stage sampling units (PSUs), and
3) the designated specific points within each sample PSU.

Data collected at the county level were:

1) total surface area subdivided into water and land area,
2) Federally owned land area, by agency,
3) urban and built-up land areas, and
4) rural land area devoted to transportation facilities and right-of-ways.

A census-type effort (NRI County Base Data) conducted in early 1982 established these acreages for each U.S. county and for each MLRA within a county. The acres of non-Federal rural land in each MLRA within a county were used for statistical expansion of the sample data. Because of the interest in urban development and to help document and track future conversions, this effort included the delineation of urban and built-up areas for both 1977 and 1982. Subsequent analyses showed, however, that these maps did not correspond to the sample data collected for urban lands. Differing interpretations and a lack of proper mapping materials lead to these inconsistencies.[2]

Data collected at the PSU level were area measurements (acres) of farmsteads, small built-up areas, small streams, small water bodies, windbreaks, critical eroding areas, and large urban and built-up areas. Most of these items are small or linear features that would be subject to bias if sampled only on a point basis.

The third level of data collection was at designated points within each PSU.[3] All land uses are included at this level so that data for such categories as farmsteads and urban and built-up areas are collected at more than one level. A ratio estimation procedure was used to combine the three levels of data.[4] One of the products of this procedure is a point data file that can be easily manipulated for use in analyzing particular resource conditions.[5] Because most resource conditions have been determined for the point samples, it is possible to cross-classify land use categories with resource conditions and characteristics.

The data collection operation for the 1982 NRI involved many thousands of people. Nearly a million points were visited either by SCS field personnel or by individuals under contract to the SCS. Data collection for the 1982 NRI began in the summer of 1980 and was concluded in the fall of 1982. Data collected before 1982 were monitored and reviewed to ensure that they reflect 1982 growing season conditions. Thus, all data are for a single point in time roughly equal to early summer of 1982.

An ongoing quality control program was an integral part of the 1982 inventory. Quality control procedures were incorporated in the SCS training, personnel supervision, and program management process. Quality control involved all management and operational levels in the SCS: field offices, area offices, state offices, the four regional national technical centers, and the National Headquarters. The state office staff was responsible for conducting field checks on a minimum of five randomly selected sample areas per county. Additional checks were made in areas of a State that indicated a need for more intense scrutiny.

The SCS National Technical Centers provided assistance on inventory aspects that required special multidisciplinary attention. This included assistance on aspects of soils, geology, agronomy, biology, engineering, recreation, and cartography. The National Technical Centers also helped coordinate activities among States to ensure uniformity and consistency in inventory data collection and processing. Ensuring uniformity and consistency required training on inventory procedures and assistance in field checking work.

The SCS National Headquarters supervised the design, implementation, scheduling, and data processing of the 1982 inventory. They also assisted States and National Technical Centers in field training on inventory procedures and conducted periodic appraisals of each State's Resources Inventory program.

Extensive use was made of computerized compatibility and edit checks during data processing. This program was a cooperative operation between the SCS and the Iowa State Statistical Laboratory. Computer edit checks were made at the Statistical Laboratory on all point and PSU data entries, and interrelationships between certain resource conditions were checked. For example, checks were done to detect incompatibilities between prime farmland and agricultural land capability (soil) class designations, and data on resource items were compared with established limits (e.g., the percent slope and length of slope that are used to estimate average annual sheet and rill erosion). Sample data failing the compatibility checks, together with comments describing the failure, were returned to the SCS state offices for reconciliation. Incompatibilities involving soils information were corrected by the state soil scientist's staff. The state resources inventory coordinator coordinated the correction of incompatibilities relating to other resource conditions.

### Sample design

Sample locations for the 1982 NRI were obtained using a stratified, two-stage, area sampling scheme. Stratification made sampling more efficient by dividing the data universe into subareas that were more homoge-

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2 J. Jeffery Goebel, Mark Reiser, and Roy D. Hickman, "Sampling and Estimation in the 1982 National Resources Inventory," paper presented at the 145th Annual Meeting of the American Statistical Association, Las Vegas, Nevada, 1985.

3 J. Jeffery Goebel and Keith O. Schmude (1982), "Quality Control and Evaluation for the SCS National Resources Inventories," *in* Place Resource Inventories: Principles and Practice. Society of American Foresters, Publication No. 82-02 (pp. 871-876).

4 Goebel, Reiser, and Hickman, *op. cit.*

5 J. Jeffery Goebel and Richard K. Dorsch, "National Resources Inventory—A Guide for Users of 1982 NRI Data Files," Soil Conservation Service, USDA, and Statistical Laboratory, Iowa State University, 1984 (revised 1986), 34p.

neous than the population as a whole. Two-stage area samples were selected within each stratum. The first stage sample unit, or primary sampling unit (PSU), was an area of land. At the second stage of sampling, one or more sample points were selected within each PSU for observation.

The first step in selecting the sample was to develop strata for the 3,100 counties in the conterminous 48 States, Hawaii, and the Caribbean. Some counties were also stratified according to broad resource and ownership conditions, which occurred most frequently in irrigated regions. In parts of the United States covered by the Public Land Survey system, geographic stratification was based upon legally described sections and townships. A section is a 1-mile square segment of land, and a township is a 6-mile square area consisting of 36 sections. Each township was subdivided vertically into three 2-mile by 6-mile strata for sampling purposes. In southeastern Ohio and for counties in the Southeastern States not covered by the Public Land Survey system, lines analogous to townships and sections were superimposed on county maps, and geographic strata were formed from 2-mile by 6-mile tracts of land. In the 13 Northeastern States, strata were formed using latitude and longitude. For Arkansas, Louisiana, and northwest Maine, sampling was based upon the Universal Transverse Mercator grid system.

The second step was to select the PSUs. The base sample consisted of 320,823 PSUs. Additional samples were selected and inventoried in 20 States to obtain more intensive data to aid in special local studies. Thus, the final 1982 NRI data base was constructed using 364,789 PSUs. These PSUs constitute a sample of about 3 percent of all the total land and water areas of the 48 conterminous States, Hawaii, and the Caribbean. The distribution of PSUs by State is shown in table A-1.

In the 34 States that have 2-mile by 6-mile strata, PSUs were generally 160-acre square parcels measuring 0.5 mile on each side. In the Western United States, PSUs were often 40- or 640-acre square parcels. The 40-acre units were used in most irrigated areas, and the larger PSUs were used in relatively homogeneous areas containing large tracts of range, forest, or barren land. In the 13 Northeastern States, PSUs were defined to be 20 seconds of latitude by 30 seconds of longitude, ranging from 97 acres in Maine to 114 acres in southern Virginia. In Louisiana and part of northwestern Maine, PSUs were 0.5 kilometer squares (61.8 acres). In Arkansas, PSUs were defined to be square kilometers of land.

The last step in selecting the sample was to locate three sample points within each PSU. There were exceptions—two points were selected from 40-acre PSUs, and only one point was selected per PSU in Arkansas, Louisiana, and northwestern Maine. In Arkansas, the center point within each PSU was selected for observation. In all other States, the points were selected randomly using a procedure designed to prevent the clustering of points within a PSU.

The procedure for selecting the points within a PSU was as follows:

1) A grid consisting of squares formed with three rows and three columns was superimposed on the PSU. Each square was subdivided into 4 equal blocks. The numbers 1 to 12 were assigned to the blocks in each row, with a number appearing once in each row and each column. No adjoining blocks had the same number.
2) Two numbers between 1 and X were selected at random, where X is the width of the side of the PSU in feet. These two numbers determine the coordinates of sample point #1 in feet north and east from the PSU's southwest corner.
3) Points #2 and #3 were located in the blocks with the same label as the block for point #1. The three points were positioned in the same relative position within the blocks.

Steps for selection of two sample points within a PSU were similar, except the PSU was divided into just 4 blocks instead of 36.

Sampling rates varied across strata, typically being between 2 and 6 percent. They generally were consistent across part or all of a county. The rate of sampling for any given stratum depended upon such factors as land use and soils patterns, MLRA distribution, and county size. The sampling scheme was basically a compromise, attempting simultaneously to balance the workload among SCS field offices and fulfill the design objectives of the study.

The total number of non-Federal rural sample points comprising the 1982 NRI was 798,790. The breakdown by State is shown in table A–1.

## Data Reliability

The NRI data base can be used to produce acreage estimates for numerous attributes and combinations of attributes. NRIs are routinely used, for example, to define the breakdown of the surface area of the U.S. into major land cover/use categories (fig. A–1 and table A–2).

The precision of these acreage estimates depends on how many samples were taken within the region of interest, the underlying distribution of the resource

characteristics in the region, and how the sample was selected. Generally, characteristics that are common and spread fairly uniformly over an area can be estimated more precisely than characteristics that are rare or unevenly distributed.

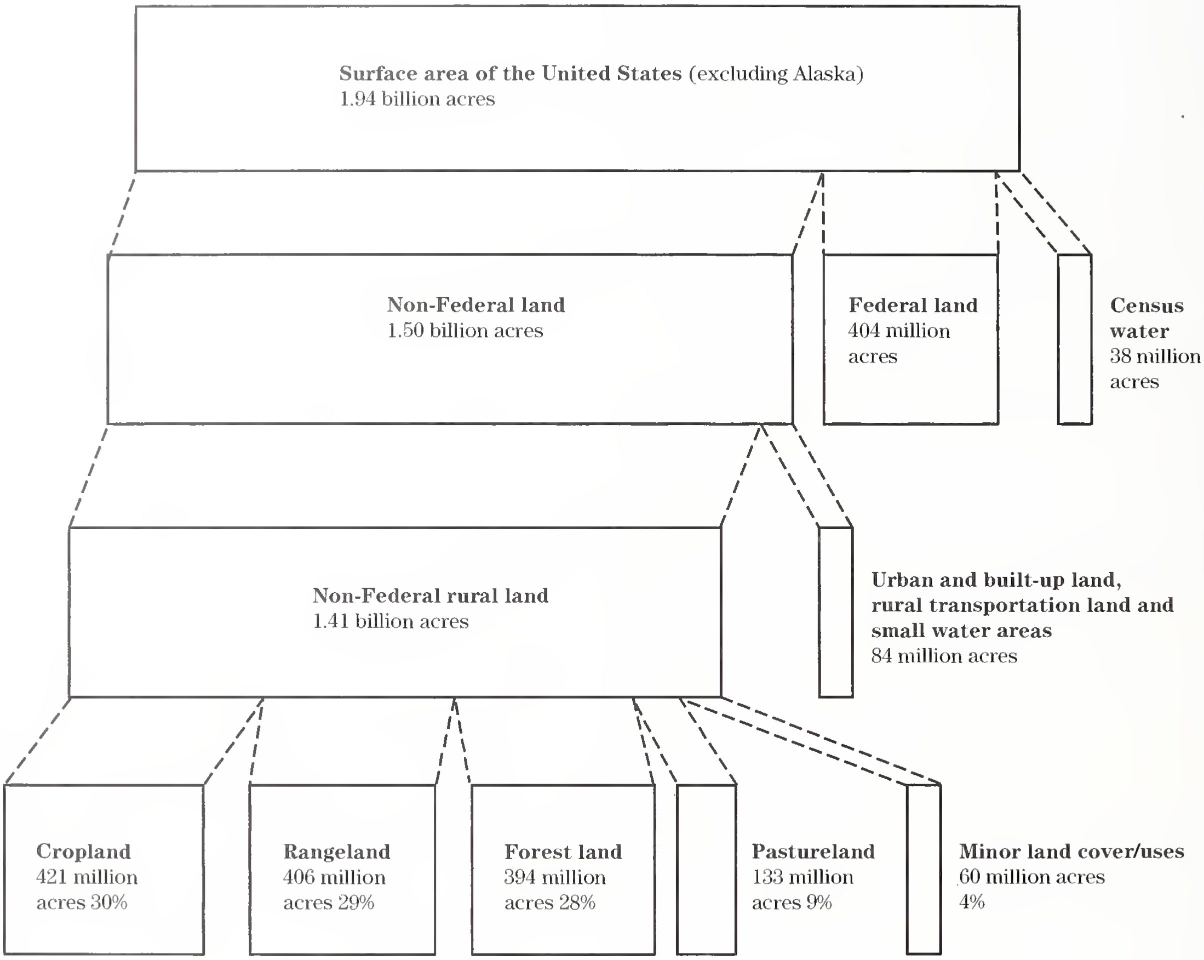
The design objective for the 1982 NRI was to have a margin of error of less than 20 percent for any estimate of a resource condition that comprises at least 10 percent of the total land area within a MLRA. Margins of error corresponding to 95 percent confidence limits (plus or minus two standard deviations) are shown in table A–2 for acreage estimates of the five major categories of land cover by State for 1982. These margins of error reflect the uncertainty in the estimate from two sources:

- **Sampling error**, which occurs when only a portion of the landscape is observed and the sampled subset is not perfectly representative of the population, and
- **Measurement error,** which occurs when data items are misclassified by the field observer or error is introduced during the recording, keypunching, or processing of the data.

To evaluate the measurement error associated with the 1982 NRI, a statistical quality evaluation study was conducted. A subsample of 3,426 sample PSUs in 502 counties was revisited by state and area office personnel, and data were collected independently of previous field visits.[6] The evaluation showed that measurement error was responsible for 5 to 10 percent of the reported margins of error for land use acreage estimates. For most other estimates the portion of the margin of error owing to measurement error is larger. For example, measurement error is responsible for 20 to 25 percent of the margins of error for estimates of sheet and rill erosion rates.

[6] Carol A. Francisco "A Quality Evaluation Study of the 1982 National Resources Inventory," final report to the Soil Conservation Service, USDA; Statistical Laboratory, Iowa State University, Ames, Iowa, 1986.

**Figure A–1** Estimating surface area and land cover/use of the United States using the 1982 NRI




Source: United States Department of Agriculture. 1987. Basic statistics—1982 National Resources Inventory. Stat. Bull. 756, Soil Conservation Service and Iowa State University's Statistical Laboratory.

**Table A–1** Sample sizes for the 1982 National Resource Inventory, by State

| | Number of PSUs included in 1982 NRI data base | Number of non-Federal rural sample points | Size of PSUs (acres) |
|---|---|---|---|
| Alabama | 6,466 | 17,174 | 160 |
| Arizona | 2,940 | 5,108 | 40, 160 |
| Arkansas | 14,080 | 11,771 | 40, 160 |
| California | 8,716 | 15,815 | 160 |
| Colorado | 7,613 | 14,514 | 160 |
| Conneticut | 1,228 | 2,350 | 105-106 |
| Delaware | 537 | 1,082 | 110 |
| Florida | 9,498 | 20,897 | 160 |
| Georgia | 8,088 | 20,130 | 160 |
| Idaho | 7,266 | 11,679 | 160 |
| Illinois | 10,684 | 28,270 | 160 |
| Indiana | 5,993 | 16,075 | 160 |
| Iowa | 7,770 | 22,077 | 160 |
| Kansas | 17,187 | 49,166 | 160 |
| Kentucky | 6,934 | 17,893 | 160 |
| Louisiana | 32,463 | 25,127 | 160, 62 |
| Maine | 2,673 | 4,401 | 62, 97-102 |
| Maryland | 3,580 | 7,214 | 109-111 |
| Massachusetts | 1,973 | 3,621 | 104, 105 |
| Michigan | 9,283 | 22,157 | 160 |
| Minnesota | 13,439 | 34,695 | 160 |
| Mississippi | 6,732 | 17,830 | 160 |
| Missouri | 10,197 | 27,387 | 160 |
| Montana | 6,355 | 14,331 | 160 |
| Nebraska | 7,583 | 21,737 | 160, 640 |
| Nevada | 5,111 | 6,421 | 40, 160, 640 |
| New Hampshire | 1,702 | 3,813 | 100-105 |
| New Jersey | 2,373 | 3,982 | 160 |
| New Mexico | 5,129 | 10,031 | 160 |
| New York | 7,140 | 17,130 | 160 |
| North Carolina | 6,681 | 15,315 | 160 |
| North Dakota | 7,367 | 20,185 | 160 |
| Ohio | 6,997 | 17,655 | 160 |
| Oklahoma | 8,211 | 22,677 | 160 |
| Oregon | 5,912 | 10,650 | 160 |
| Pennsylvania | 10,279 | 24,310 | 105-108 |
| Rhode Island | 667 | 1,136 | 160 |
| South Carolina | 8,256 | 19,871 | 160 |
| South Dakota | 7,090 | 19,788 | 160, 640 |
| Tennessee | 7,763 | 19,464 | 160 |
| Texas | 24,258 | 65,317 | 160 |
| Utah | 4,009 | 5,439 | 40, 160, 640 |
| Vermont | 2,662 | 6,397 | 101, 102 |
| Virginia | 9,012 | 20,238 | 110-114 |
| Washington | 6,127 | 12,519 | 160 |
| West Virginia | 4,900 | 12,755 | 109-112 |
| Wisconsin | 7,138 | 18,049 | 160 |
| Wyoming | 3,898 | 8,295 | 160, 640 |
| **48 State Total** | **361,960** | **793,938** | |
| Hawaii | 406 | 1,008 | 160 |
| Caribean | 2,423 | 3,844 | 40 |
| **Grand Total** | **364,789** | **798,790** | |

Source: U.S. Department of Agriculture (1987) "Basic Statistics—1982 National Resources Inventory," Statistical Bulletin No. 756, Soil Conservation Service and Statistical Laboratory, Iowa State University, Table E1.

**Table A–2** Estimated acres (thousands) of major cover/land use categories in 1982 by State (estimated margins of error in thousands of acres are in parentheses)

| | Cropland | | Pastureland | | Rangeland | | Forest land | | Miscellaneous | |
|---|---|---|---|---|---|---|---|---|---|---|
| Alabama | 4,510 | (198) | 3,817 | (184) | 0 | | 20,633 | (281) | 557 | (89) |
| Arizona | 1,206 | (110) | 79 | (51) | 30,948 | (935) | 4,760 | (629) | 2,574 | (560) |
| Arkansas | 8,102 | (161) | 5,794 | (197) | 165 | (40) | 14,340 | (223) | 325 | (54) |
| California | 10,518 | (427) | 1,393 | (189) | 18,125 | (870) | 15,218 | (657) | 4,372 | (599) |
| Colorado | 10,603 | (467) | 1,260 | (161) | 24,223 | (772) | 4,030 | (421) | 1,056 | (208) |
| Conneticut | 245 | (32) | 114 | (26) | 0 | | 1,828 | (61) | 142 | (27) |
| Delaware | 519 | (38) | 35 | (11) | 0 | | 348 | (33) | 122 | (22) |
| Florida | 3,557 | (189) | 4,273 | (228) | 3,804 | (197) | 12,430 | (247) | 3,554 | (196) |
| Georgia | 6,568 | (221) | 2,977 | (157) | 0 | | 21,884 | (324) | 956 | (91) |
| Idaho | 6,390 | (270) | 1,274 | (123) | 6,733 | (316) | 3,977 | (214) | 533 | (101) |
| Illinois | 24,727 | (229) | 3,157 | (139) | 0 | | 3,429 | (147) | 623 | (68) |
| Indiana | 13,781 | (195) | 2,212 | (122) | 0 | | 3,640 | (137) | 813 | (92) |
| Iowa | 26,441 | (232) | 4,536 | (172) | 0 | | 1,756 | (115) | 923 | (90) |
| Kansas | 29,118 | (304) | 2,241 | (120) | 16,909 | (343) | 626 | (60) | 711 | (68) |
| Kentucky | 5,934 | (167) | 5,880 | (165) | 0 | | 10,158 | (197) | 785 | (81) |
| Louisiana | 6,409 | (112) | 2,369 | (93) | 241 | (24) | 12,895 | (121) | 3,234 | (64) |
| Maine | 953 | (45) | 569 | (43) | 0 | | 16,770 | (80) | 652 | (58) |
| Maryland | 1,794 | (71) | 534 | (39) | 0 | | 2,425 | (82) | 352 | (38) |
| Massachusetts | 297 | (40) | 202 | (31) | 0 | | 2,970 | (77) | 305 | (41) |
| Michigan | 9,443 | (205) | 2,911 | (149) | 0 | | 15,360 | (236) | 2,168 | (139) |
| Minnesota | 23,024 | (310) | 3,590 | (226) | 199 | (32) | 13,956 | (538) | 4,165 | (273) |
| Mississippi | 7,415 | (207) | 3,975 | (191) | 0 | | 15,243 | (306) | 354 | (56) |
| Missouri | 14,998 | (247) | 12,573 | (297) | 168 | (40) | 10,986 | (282) | 707 | (79) |
| Montana | 17,197 | (684) | 3,036 | (322) | 37,837 | (1,017) | 5,228 | (486) | 1,346 | (263) |
| Nebraska | 20,277 | (353) | 2,125 | (150) | 23,096 | (432) | 732 | (98) | 737 | (94) |
| Nevada | 860 | (156) | 304 | (70) | 7,908 | (405) | 357 | (87) | 353 | (76) |
| New Hampshire | 158 | (26) | 125 | (27) | 0 | | 4,085 | (84) | 195 | (36) |
| New Jersey | 809 | (51) | 240 | (37) | 0 | | 1,848 | (67) | 386 | (36) |
| New Mexico | 2,413 | (220) | 163 | (32) | 40,982 | (1,099) | 4,734 | (657) | 2,199 | (447) |
| New York | 5,912 | (192) | 3,872 | (164) | 0 | | 16,517 | (249) | 724 | (83) |
| North Carolina | 6,695 | (232) | 1,980 | (133) | 0 | | 16,729 | (285) | 811 | (94) |
| North Dakota | 27,039 | (344) | 1,272 | (127) | 10,948 | (315) | 438 | (71) | 1,301 | (132) |
| Ohio | 12,447 | (195) | 2,714 | (132) | 0 | | 6,380 | (199) | 1,055 | (92) |
| Oklahoma | 11,568 | (278) | 7,138 | (267) | 15,060 | (316) | 6,539 | (227) | 421 | (64) |
| Oregon | 4,356 | (225) | 1,966 | (177) | 9,382 | (396) | 11,889 | (487) | 628 | (108) |
| Pennsylvania | 5,896 | (160) | 2,593 | (121) | 0 | | 15,300 | (253) | 1,053 | (84) |
| Rhode Island | 27 | (7) | 36 | (8) | 0 | | 406 | (16) | 29 | (8) |
| South Carolina | 3,579 | (116) | 2,308 | (86) | 0 | | 11,026 | (162) | 726 | (56) |
| South Dakota | 16,947 | (374) | 2,703 | (187) | 22,784 | (455) | 562 | (90) | 1,498 | (138) |
| Tennessee | 5,592 | (161) | 5,356 | (178) | 0 | | 11,529 | (256) | 581 | (64) |
| Texas | 33,320 | (565) | 17,043 | (412) | 95,353 | (766) | 9,324 | (243) | 2,164 | (211) |
| Utah | 2,039 | (192) | 490 | (96) | 8,489 | (562) | 3,235 | (581) | 1,971 | (467) |
| Vermont | 648 | (49) | 501 | (43) | 0 | | 4,087 | (77) | 79 | (17) |
| Virginia | 3,397 | (143) | 3,392 | (128) | 0 | | 13,625 | (210) | 686 | (60) |
| Washington | 7,793 | (285) | 1,345 | (137) | 5,637 | (330) | 12,690 | (297) | 914 | (137) |
| West Virginia | 1,093 | (79) | 1,869 | (99) | 0 | | 10,423 | (145) | 283 | (39) |
| Wisconsin | 11,457 | (240) | 3,394 | (159) | 0 | | 13,393 | (258) | 2,438 | (151) |
| Wyoming | 2,587 | (323) | 755 | (168) | 26,915 | (1,089) | 987 | (252) | 980 | (335) |
| **48 State Total** | **420,658** | | **132,485** | | **405,906** | | **391,725** | | **53,541** | |
| Hawaii | 333 | (65) | 974 | (194) | 0 | | 1,474 | (322) | 827 | (298) |
| Caribean | 408 | (32) | 955 | (40) | 0 | | 517 | (39) | 52 | (12) |
| **Grand Total** | **421,399** | | **134,414** | | **405,906** | | **393,716** | | **54,420** | |

Note: The lower limit of a 95 percent confidence interval can be determined by subtracting the margin of error from the estimated acreage value; the upper limit is determined by adding the margin of error to the acreage estimate.

Source: U.S. Department of Agriculture (1987) "Basic Statistics—1982 National Resources Inventory," Statistical Bulletin No. 756, Soil Conservation Service and Statistical Laboratory, Iowa State University, Table G1.

# Appendix B: A Cartographic Data Base for Analyzing the National Resource Inventory and SOI-5 Data Bases in a Geographic Information System

**Margaret Stewart Maizel and George B. Muehlbach**
National Center for Resource Innovations

The 1982 National Resources Inventory (NRI) and SOI-5 data bases of the USDA Soil Conservation Service were used by Kellogg, Maizel, and Goss in this publication to assess the potential for contamination of ground water by leaching of agrichemicals at the national level.

The key to analysis of the NRI-SOI-5 data bases in a Geographic Information System (GIS) lies in the fact that each of the 1982 NRI sample points carries an identifier for the county, Major Land Resource Area (MLRA), and the hydrologic unit in which it is located. A national digital cartographic data base was created by overlaying the boundaries of 3,041 counties, 209 MLRA's, 2,111 hydrologic units and Federal lands for the conterminous United States. The polygons created by intersections of these boundary overlays provide geographically identifiable locations for referencing and distributing each sample point in the inventory among non-Federal rural and Indian lands. These polygons, together with the collection of NRI sample points belonging to them, 1) permit analysis based on site-specific, co-located information on land use, soil type, and other geographically referenceable overlays, such as average annual precipitation and climate; and 2) provide physiographical units for aggregating to larger regions by taking advantage of the statistical properties of the NRI data base.

The purpose of this appendix is to describe the cartographic data base, how it was developed, and its relationship to the NRI-SOI-5 data bases.

The original NRI-SOI-5 cartographic data base was built using polygon overlay techniques at the Harvard Laboratory for Computer Graphics and Spatial Analysis under a grant from the Laurel Foundation to the American Farmland Trust. Considerations in selecting a vector (over a raster) format included the precision, flexibility, and relatively low "overhead" in information management offered by vector systems. Descriptions of the data base and sources for components have been published previously.[1]

This early work demonstrated the feasibility of using the NRI in a GIS framework for natural resource assessment and conservation policy development. For example, potential multiple benefits of the Conservation Titles of the 1985 and 1990 Farm Bills in protecting not only highly erodible cropland, but also surface and ground water resources and specific endangered species habitats, were demonstrated in a study for the U.S. Environmental Protection Agency's Office of Policy Analysis in 1989 (Contract No 68-01-7233). Components of the Soil-Pesticide Interaction Screening Procedure were described in 1989 for the Congressional Office of Technology Assessment's ground water study "Beneath the Bottom Line."

## Building the Cartographic Data Base

As distributed by SCS, the 1982 NRI includes 797,051 sample points describing the 1.41 billion acres of non-Federal rural lands. This includes 52 million acres of Indian tribal and individual trust lands.

### Components of the data base

For these studies, the cartographic data base was converted to ARC/INFO format, version 5.1. The data base management system used for the NRI and SOI-5 data bases was Informix version 4.1. Four principal data layers were used to construct the original cartographic data base:

(1) *Major Land Resource Areas* (MLRA's) as of 1984 consisting of 204 polygons in the conterminous United States describing 189 MLRAs, some of which are present in more than one polygon.[2]

(2) *Hydrologic Units*, consisting of 2,111 polygons carrying 8-digit identifiers defining accounting units, cataloging units, subregional and regional watershed

[1] White, D., M. Maizel, K. Chan, and J. Corson-Rikert. 1989. "Polygon Overlay to Support Point Sample Mapping: the National Resources Inventory." Auto-Carto TX, Baltimore, MD, pp. 33-37.

[2] "Land Resource Regions and Major Land Resource Areas of the United States." United States Department of Agriculture, Agriculture Handbook 296, revised 1981.

and administrative boundaries of the U.S. Water Resources Council.[3]

(3) *Non-Federal boundaries.* Counties, States, and other minor jurisdictions are represented by 3,143 polygons containing 3,041 county, State, and other minor jurisdictional boundaries as distributed by the U.S. Bureau of the Census for 1980.

(4) *Federal lands.* Federal lands boundaries (1:2 million scale, DLG-3 format outlining 23 different jurisdictions within more than 1,000 polygons) were obtained from the U.S. Geological Survey and included Indian lands. These Federal lands boundaries constitute the exclusion screen for polygons where the NRI is not collected. Since the NRI is collected on the 52 million acres of Indian Lands, polygons defining Indian lands were removed from the exclusion screen to allow the underlying polygons to be properly mapped.

The Bureau of Land Management (BLM), U.S. Department of the Interior, has jurisdiction over approximately 321 million acres of Federal lands located primarily in 11 western states. Boundaries defining BLM lands are not included in the Federal lands file. After examination within the context of other Federal lands boundaries and the NRI map base, we decided the complexity of in- and out-holdings overlapping jurisdictions with other Federal lands and apparent state-based differences in coordinate systems[4] would make this data layer relatively unusable. It was therefore not incorporated into the exclusion screen. Care, therefore, should be exercised in examining data in western States, such as Nevada, New Mexico, Arizona, Wyoming, Montana, and western Colorado, where BLM lands predominate. In these States the areal extent of mapping polygons is over-represented because of the lack of the BLM Federal lands exclusion screen.

### Refining the data base

The NRI data base as originally constructed from these diverse sources was composed of 60,000 polygons. Coarsening was used to reduce the polygon population to about 35,000 by eliminating those polygons that would be smaller than about 1.5 square kilometers without eliminating authentic polygons to which NRI points might match.

After further editing, the total number of polygons in the cartographic data base was 27,795. The resulting map base is shown in figure B–1.

The average size of the polygons is 95,190 acres, ranging between a minimum of 100 acres and a maximum of 2,288,000 acres.

### Characterizing the cartographic data base

To characterize the cartographic data base and its elementary relationship to the NRI attribute data base, a convention was adopted to describe mapping and non-mapping polygons in the map base.

Mapping polygons in the cartographic data base are defined to be those polygons to which one or more sample points match by virtue of their common geocodes. The areal extent of the mapping polygons is shown in figure B–1.

Non-mapping polygons are those to which no NRI sample points match. These polygons are also shown in figure B–1. The non-mapping polygons are divided into two classes: (1) those within Federal lands jurisdictions where the NRI is not collected, and (2) those for which there are no matching NRI points. This includes urban/built-up areas, such as are visible in Virginia and incorporated cities. Other non-mapping polygons correspond to transportation and census water areas for which 1982 NRI sample points are not available. Certain others of these polygons may also result from the statistical sampling distribution of the NRI.

Of the 27,795 polygons in the map base, 7,883 non-mapping polygons were within Federal lands. An additional 3,745 non-mapping polygons are in the map base outside Federal lands.

### Least Common Geographical Units: Unique polygons

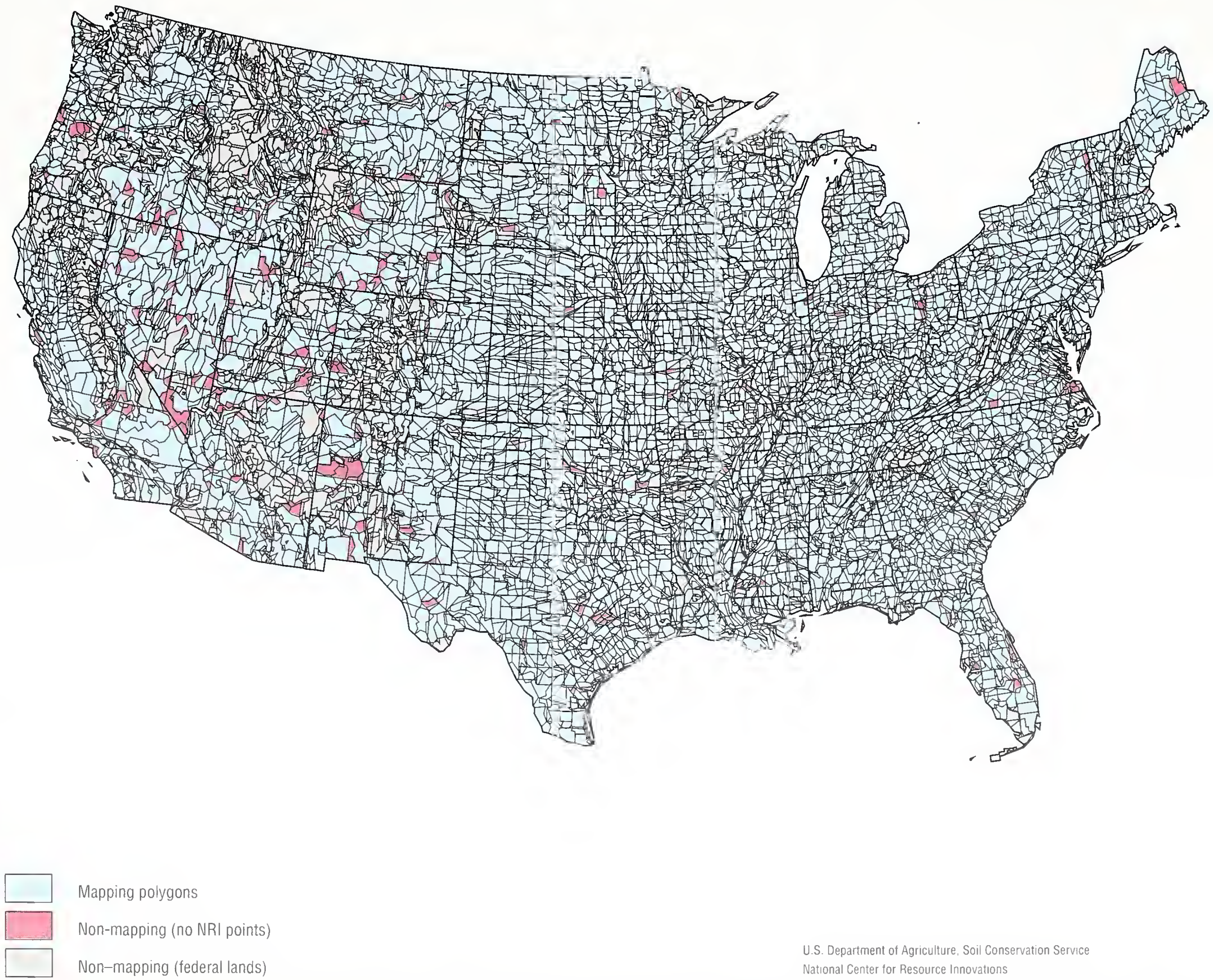
Optimally, the technique of polygon overlay used to create the NRI cartographic data base is expected to produce a network of Least Common Geographical Units (LCGU's),[5] that is, a set of new polygons, each of which is defined by a unique geocode. (A geocode is a one-of-a-kind locator in a geographically referenced grid — in this case the polygon map base.) This new geocode, of which there should be one and only one copy, is a composite of the county, MLRA, and hydrologic unit geocodes that formed them.

Frequency analysis showed that the total number of unique geocodes (LCGU's) among mapping polygons was 13,120, yet the total number of polygons to which NRI

[3] White, D., M. Maizel, K. Chan, and J. Corson-Rikert, *op.cit.*
[4] Gilson, Homer L. 1992. "BLM's geographic coordinate data base is it a step in the right direction?" Urban and Regional Information Systems Association 1992 Annual Conference Proceedings, vol. 1.

[5] Poiker, T.K., and N.R. Chrisman. 1975. Cartographic Data Structures. The American Cartographer, 2(1):55-69.

**Figure B–1** The cartographic data base



points were mapped was 17,120. This suggested that some non-unique mapping polygons are indeed present in the cartographic data base. For comparison, the maximum number of unique geocodes in the NRI sample point data base was determined to be 14,801. This established the maximum possible domain of mapping polygons.

Many factors peculiar to this data base contribute to its complexity.

1. *Component cartographic data layers were from different sources*—The parental polygon layers comprising the NRI cartographic data base were derived from different sources at somewhat different scales and were characterized by different degrees of detail.[6] Since they were not originally intended to be used together, cartographic and even physiographic boundaries can be expected to vary when they should coincide and appear to be identical when they ought to be spatially different. This applies to not only MLRA and hydrological unit boundaries, but also to jurisdictional boundaries, which in many instances had not been reconciled with physiographic boundaries.

2. *Overlaying the Federal lands boundaries introduced significant complexity to the cartographic data base*—A graphical description of the possible combinations of polygon structures in the cartographic data base is outlined in figure B–2. Given the disparate sources of data layers and the complexity introduced by overlaying the Federal lands boundaries, it was essential to precisely characterize the cartographic data base and its exact relationship to the NRI.

**Unique and non-unique mapping polygons in the cartographic data base**

Optimally NRI sample points should map to one, and only one polygon in the map base. Because this was not possible, it was important to document the number of unique and non-unique polygons among mapping and non-mapping polygon groups. A summary of the entire relationship is presented at the end of this appendix. A description of the mapping polygons and matching NRI points follows.

6 White, D., M. Maizel, K. Chan, and J. Corson-Rikert. *op. cit.*

## Embedding the NRI Within the Cartographic Data Base

**Classifying the NRI cartographic data base: a family album**—A classification system to account for all polygons in the cartographic data base and all matching NRI sample points was devised.

*Family:* The geocode identifier for all polygons and all sample points—The polygons in the original map base were sorted in ascending order by FIPS, MLRA, and hydrologic unit codes. They were then given sequential numbers, consisting of a 5-digit family number ranging from 10 through 18,540. After processing and further editing, 1,408 geocodes were deleted. For this study, the actual number of families (geocodes) remaining was 17,120.

*Case:* Geocode identifier for mapping polygons and sample points—Out of the total 18,530 geocodes in the map base, a total of 13,172 matched NRI sample points. These polygons, by definition mapping polygons, were given a case number equivalent to the family number.

The case number was transferred also to NRI sample points with matching geocodes.

"Case" thus became the principal pointer-identifier between NRI sample points and the mapping polygons to which their geocodes match. Where a polygon geocode was not in the NRI sample point data base, case for the non-mapping polygon was set to 0. There were 3,078 families (geocodes) in the map base for which there were no matching NRI data.

*A mapping polygon then, would have a family equal to case. Non-mapping polygons have a family with case equal to 0.*

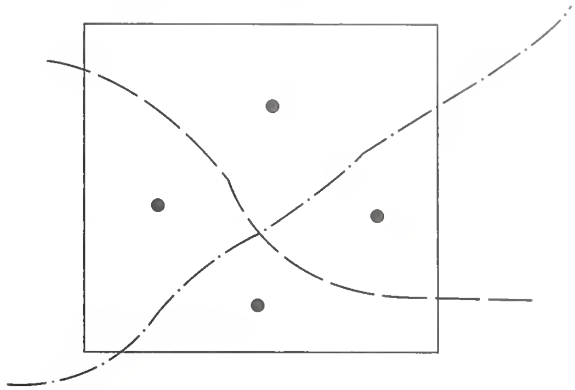
*Num:* An identifier for multiple mapping polygons—To account for multiple copies of polygons with shared geocodes, replicated polygons in mapping and non-mapping families were ordered by decreasing physical size. Unique polygons (single polygons with single copy geocodes) received a number (num)= 0. The largest polygon of a two-copy pair with a single geocode was given a num=1, the second, num=2.

*Code:* A summary identifier for mapping and non-mapping polygons—A fourth identifier, code, contained the family number followed by "num" for mapping polygons. Code for non-mapping polygons was a 5-digit 00000 followed by a "1" for polygons within Federal lands jurisdictions and a "2" for those outside those jurisdictions.

**Figure B–2** Structures in the cartographic data base

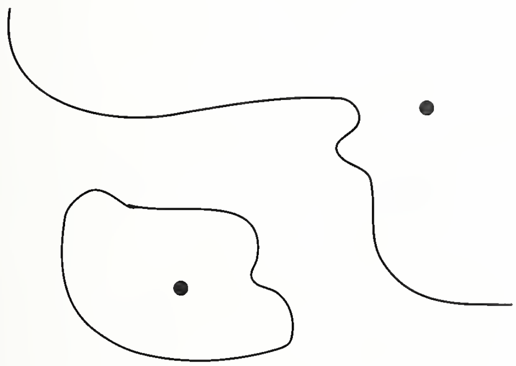
***Unique mapping polygons***—One-of-a-kind polygons created by intersections of county, MLRA, and Hydrologic Unit boundaries.

County boundary ———
MLRA boundary — • — •
Hydrologic Unit boundary — — —
(• marks examples)

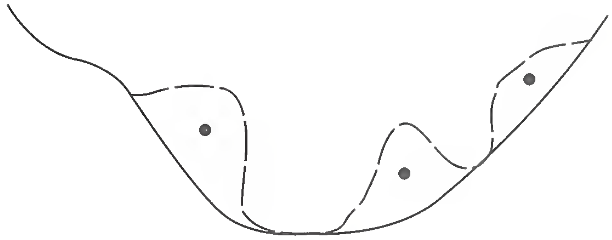


***Non-unique mapping polygons***—Polygons created by intersections of county, MLRA, and Hydrologic Unit boundaries, but which are replicated one or more times in the Cartographic data base. These polygons arise from:

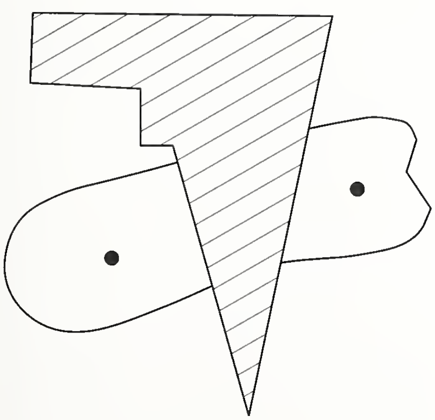
**Off-shore islands and other physically separate polygons** belonging to the same physiogrphic and jnurisdictional units (• marks related polygons).



**Long, narrow parallel polygons** or sections of polygons whose boundaries, because of their periodic closenesss to each other, have been joined during processing of the data base (• marks related polygons).



**Unique polygons split by Federal lands** (• marks related polygons).



**Cartographic noncoincidence** or otherwise common jurisdictional and physiographic boundaries—caused by the independent sources of data layers or by the actual differences in delineations of boundary locations. *Note: These need to be reconciled by appropriate agencies before they can be optimally used in an integrated format* (• marks related polygons).

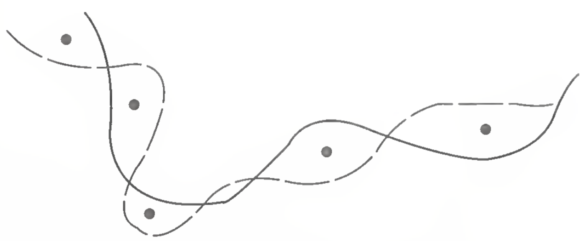
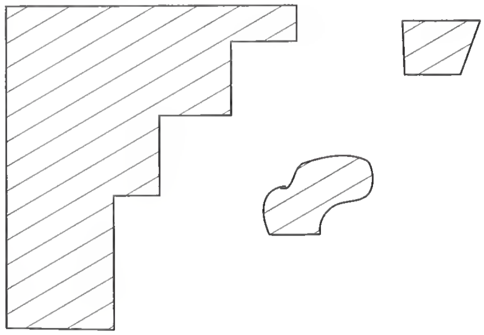


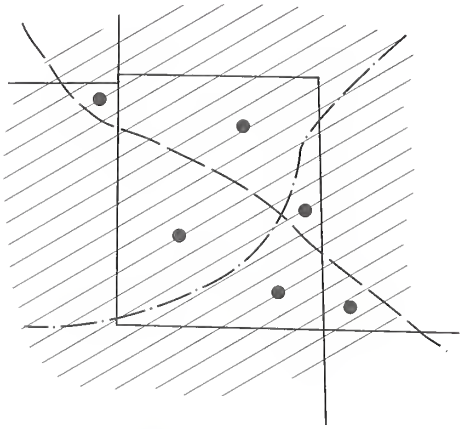
**Figure B–2** Structures in the cartographic data base—*Continued*

*Non-mapping polygons*—Polygons with all possible attributes of mapping polygons described above, but to which NRI points do not match through their geocodes. These include:

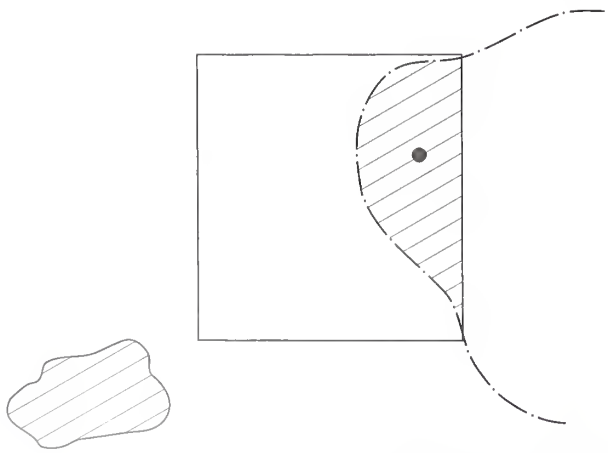
**Federal lands**



**Polygons that are wholly contained within Federal land jurisdictions** (• marks related polygons).



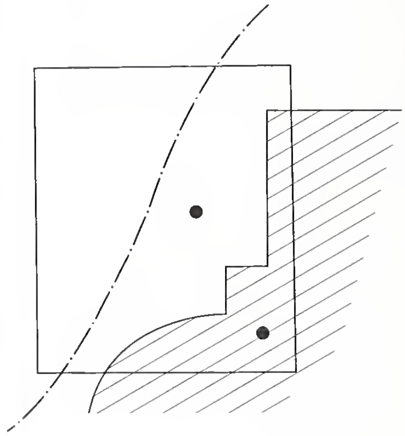
**Polygons outside of Federal lands** that, because of the statistical sampling protocol, co-location of polygons with urban/buillt-up, transporatation, or census water areas, do not have complementary NRI sample points (• marks related polygons).



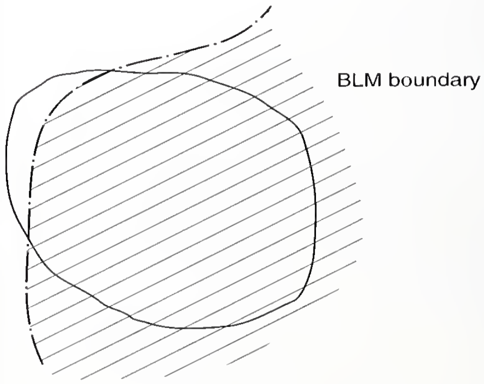
**Other polygons**

**Missing polygons:** Polygons that may be ampping or non-mapping, but that are lost from the data base because of processing of small polygons.

**Polygons transected by Federal lands.** (Note: These polygons should be carefully assessed because they will be smaller than the geographic areas referred to by sample point expansion factors.)



**Polygons whose area is exaggerated** because of the lack of an appropriate BLM (Federal land) exclusion layer. (Note: These polygons are in the 11 Western States, most notably in Nevada and Utah.)



An example set of codes for seven polygons in one neighborhood follows in table B–1.

Polygons A, B, C, D, and E belong to one family (18523) in Weston County, which is in the Pierre Shale Plains and Badlands (MLRA) in northeast Wyoming in an upper cataloging unit of the Cheyenne River. Polygon A is non-mapping (case = 0) because it is under Federal jurisdiction (code 000001). Polygon E is non-mapping because no geocode matches to NRI points (code = 000002).

Of the three mapping polygons, B, C, and D, none is unique (nums 1, 2, and 3, respectively). There are 135 NRI sample points matching this geocode whose expansion factors add up to about 27,620 acres (data not shown). This geocode is divided among the three polygons with num = 1 being the largest and num = 3, the smallest. The value that would be ascribed to polygon B is also ascribed to C and D in maps.

Polygons F and G are unique mapping polygons (num = 0) in nearby cataloging units of the same county except that polygon G is in the northern part of the Northern Rolling High Plains (MLRA 58B). Ten NRI sample points whose expansion factors add up to 55,100 acres match Polygon F, and 36 points whose expansion factors add up to 72,200 acres match polygon G (data not shown).

**Sizes of mapping polygon families**

A description of the sizes of all mapping polygon families is shown in table B–2. Areas of these polygons are calculated from the sum of the expansion factors of NRI points with matching geocodes. As the number of geocodes in a group decreases, confidence levels for these acreages also decline. Acreages are presented for the highest copy numbers only to provide relative estimates of areas covered.

**Table B–1** Examples of polygon codes in three neighboring families

| Poly | Code | Family | Case | Num | FIPS | MLRA | Hydro Unit |
|---|---|---|---|---|---|---|---|
| A | 000001 | 18523 | 0 | 1 | 56045 | 60A | 10120107 |
| B | 185231 | 18523 | 18523 | 1 | 56045 | 60A | 10120107 |
| C | 185232 | 18523 | 18523 | 2 | 56045 | 60A | 10120107 |
| D | 185233 | 18523 | 18523 | 3 | 56045 | 60A | 10120107 |
| E | 000002 | 18524 | 0 | 2 | 56045 | 60A | 10120107 |
| F | 185210 | 18521 | 18521 | 0 | 56045 | 60A | 10120106 |
| G | 185190 | 18519 | 18519 | 0 | 56045 | 58B | 10121210 |

Among the mapping polygons, 11,120 were determined to be truly unique. These polygons accounted for 1,162,951,500 acres, or 85.4 percent of the non-Federal rural land as described in these maps by expansion factors associated with the 682,873 NRI sample points (88% of the mapping sample points) which matched them.

Another 1,508 geocodes were found in pairs of polygon copies. These accounted for 137,583,300 acres (an additional 10%) of non-Federal rural lands, as characterized by the 68,279 sample points matching them. Three hundred and thirty-six other geocodes were replicated in groups of three polygons covering 36,151,200 acres (2.7% of the map base), as characterized by 15,421 NRI sample points. One hundred and twenty-three other geocodes characterized by 4,938 NRI sample points were found in four-copy groups, and so on.

One geocode was found in a group of 11 polygons, none were found in groups of 12, 13, or 14, but one with 17 NRI sample points was found in the largest family of 15.

Figure B–3 shows the location of unique polygons (copies = 1) and non-unique polygons (copies ≥ 2) in the map base. While many duplex polygons are found amid large areas of unique polygons in the body of maps, most of the largest families are associated with complex Federal land/mapping polygon intersections. An example of this can be seen by examining the southwestern corner of Montana in this map.

**Table B–2** Sizes of mapping polygon families

| Number of copies of polygon | Number of NRI geocodes | Number of NRI sample points | % of NRI sample points in data base | Million acres | % of acres in data base |
|---|---|---|---|---|---|
| 1 (unique) | 11,121 | 682,990 | 88.1 | 1,163.866 | 86.1 |
| 2 | 1,507 | 68,147 | 8.8 | 137.469 | 10.1 |
| 3 | 336 | 15,421 | 2.0 | 36.151 | 2.7 |
| 4 | 123 | 4,938 | 0.6 | 12.976 | 1.0 |
| 5 | 41 | 1,727 | 0.2 | 5.078 | 0.4 |
| 6 | 14 | 665 | 0.1 | 1.648 | 0.1 |
| 7 | 16 | 519 | 0.0 | 2.633 | 0.2 |
| 8 | 6 | 311 | 0.0 | 1.011 | 0.0 |
| 9 | 4 | 248 | 0.0 | 0.988 | 0.0 |
| 10 | 2 | 43 | 0.0 | 0.313 | 0.0 |
| 11 | 1 | 29 | 0.0 | 0.071 | 0.0 |
| 15 | 1 | 17 | 0.0 | 0.033 | 0.0 |
| **Total** | **13,172** | **775,055** | **100** | **1,361.437** | **100** |

**Distribution of NRI sample points among polygons in the map base**
It is useful to know the number of NRI sample points in each polygon in the map base. This distribution is not expected to be uniform primarily because of variations in sample rates[7] and polygon size. Figure B–4 shows the number of sample points in each polygon in the map base. The minimum number of sample points in mapping polygons was found to be 1. The average was 53.8, and the maximum—in Lancaster County, Pennsylvania (also one of the largest polygons)—was 710 sample points.

**Density of NRI sample points per polygon**
Generally, the confidence level of NRI data decreases with decreasing geographic area.[8] However, 95 counties have "densified" the NRI to provide county-level data and some states have developed NRI sampling rates more intensively than others.[9] Figure B–5 shows the density of NRI sample points in the map base per 10,000 acres. Interestingly, county boundaries emerge in these maps—as is most easily seen in areas of highest NRI densities—illustrating the county-oriented stratification protocol.[10]

**Acreage by State of the non-Federal rural land included in the analytical framework**
Many analyses in this series are presented as aggregate data at the State level. Table B–3 accounts for NRI sample points by State.

**Summary**
Figure B–6 is a cartogram that summarizes the relationship between NRI sample points and the cartographic data base. It accounts for geocodes among unique and non-unique polygons and NRI points as well as mapping and non-mapping polygons as used in this series of studies. The approximate areal extent of each category of polygons is spatially represented.

The outer boundaries of the two largest rectangles delineate the approximate spatial extent and relationship between mapping and non-mapping polygons within and outside Federal lands. The box overlapping non-mapping and mapping polygons on non-Federal lands represents the spatial extent of non-unique mapping and non-mapping polygons.

About 97 percent of the NRI points match the map base that covers 93 percent of the non-Federal rural and Indian lands in the conterminous United States. A significant majority of the mapping sample points (84.5%) are associated with unique mapping polygons that account for 80 percent of the non–Federal rural lands.

Non-unique polygons cover 13 percent of the map base and 11.4 percent of the sample points are associated with them. Future work could reduce this further, but not without some cartographic judgment that would not necessarily relate to the physiographic world.

The non-mapping polygons in the cartographic data base outside of Federal lands represent 7 percent of the land base.

The 21,981 sample points that failed to match the map base include 1,617 points for Hawaii and the Caribbean, 660 sample points for multijurisdictional Indian lands, other points for which polygons may have been deleted in processing of the data base, and a certain number of sample points with nonsensical identifiers.

We are in the process of refining this data base with respect to BLM lands, non-unique polygons, and non-mapping NRI sample points.

## Representing NRI Attributes in Choropleth Maps

Choropleth maps were constructed using the cartographic data base to show the spatial distribution of NRI attributes. Choropleth maps are maps in which areas within distinct boundaries are shaded uniformly. When mapped, each polygon in the cartographic data base has a single color that represents some aggregate measure of an attribute of the NRI sample points in that polygon. For example, the *percentage of a polygon that is cropland* is an aggregate measure that is based on all of the NRI sample points in that polygon. The average of an attribute, such as the *average percolation factor* shown in figure 5 is another example. In all cases, the attribute values for the NRI points within a polygon are converted into a single value that represents the polygon and is used to determine the color assignment. Expansion factors—the acreages that the NRI points represent—are involved in all calculations of NRI attributes.

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7 Goebel, J., and R.K. Dorsche *op. cit.*, and Goebel, J., this series.
8 "Basic Statistics, 1982 National Resources Inventory" *op. cit.*
9 Goebel, J., and R.K. Dorsche *op cit.*
10 Goebel, J., and R.K. Dorsche *op. cit.*

This publication contains three basic types of maps that are distinguished by the nature of the aggregate measure of the NRI attribute: percent area maps, average value maps, and total value maps.

**Percent area maps** are the most common. The aggregate measure determined for each polygon in these maps is the percent of the polygon area where the attribute meets a specified criteria, determined as:

$$\text{Percent area of mapping polygon} = \frac{\sum_{i=1}^{N} \text{EXPAND}_i^*}{\sum_{i=1}^{N} \text{EXPAND}_i}$$

where:

$i$ = 1,2,3, . . .N NRI points in a mapping polygon.

$\text{EXPAND}_i^*$ = expansion factor in acres for NRI points that meet a specific criterion.

$\text{EXPAND}_i$ = expansion factor in acres for an NRI point.

This calculation may be done using all points in the polygon or using only those designated as cropland, depending on what is needed. Examples of the former include maps of the *percent area* with soils that have a *High/Intermediate/Low/Very Low Soil Leaching Class* (figs. 1–4). An example of the latter is the *percent of cropland area* with a ground water vulnerability index for pesticides less than 30 (fig. 12).

**Average value maps** use an area-weighted average to represent the polygon. Expansion factors are used as the weights so that each point contributes to the average according to its relative representativeness. The calculation for the weighted average of an NRI attribute is:

$$\frac{\sum_{i=1}^{N} \text{EXPAND}_i \times \text{ATTRIBUTE}_i}{\sum_{i=1}^{N} \text{EXPAND}_i} = \text{Polygon average}$$

This calculation may also be done using all points in the polygon or using only those designated as cropland. The figures for the average ground water vulnerability indexes for pesticides and for nitrogen fertilizer (figs. 10 & 11) were done this way, using all points in the polygon. The map showing the average excess nitrogen fertilizer applied per cropland acre (fig. F–1) is an example where the calculation was based only on the cropland points in the polygon.

**Total value maps** were used to show the distribution of chemical expenses (figs. 7 & 8) and figures B–4 and B–5 in this appendix. In these cases an attribute total for the polygon is used.

Expression of values in non-unique mapping polygons present a special challenge for mapping attributes. The collection of NRI points associated with the multiple polygons cannot be divided among them. For mapping NRI attributes to non-unique polygons, the attribute of the geocode was distributed evenly to all polygons of the family as if they were one.

**Table B–3** Acreage by State of non-Federal rural land included in the analytical framework

| State | Cartographic data base: Number of NRI points included | Cartographic data base: Non-Federal rural land (1,000 acres) | 1982 NRI data base Non-Federal rural land (1,000 acres) | % acres in cartographic data base |
|---|---|---|---|---|
| Alabama | 16,918 | 29,130 | 29,697 | 98.1 |
| Arizona | 4,835 | 35,513 | 39,582 | 88.5 |
| Arkansas | 11,383 | 27,960 | 28,770 | 97.1 |
| California | 15,017 | 47,240 | 49,833 | 94.5 |
| Colorado | 13,775 | 38,618 | 41,271 | 93.1 |
| Connecticut | 2,330 | 2,310 | 2,401 | 96.0 |
| Delaware | 1,065 | 1,013 | 1,039 | 97.5 |
| Florida | 20,440 | 26,779 | 27,730 | 96.4 |
| Georgia | 19,839 | 32,016 | 32,536 | 98.4 |
| Idaho | 11,052 | 18,032 | 18,934 | 95.0 |
| Illinois | 28,039 | 31,637 | 32,076 | 98.6 |
| Indiana | 15,752 | 20,047 | 20,597 | 97.3 |
| Iowa | 21,896 | 33,358 | 33,709 | 98.9 |
| Kansas | 48,725 | 48,949 | 49,655 | 98.6 |
| Kentucky | 17,678 | 22,392 | 22,866 | 97.9 |
| Louisiana | 24,137 | 24,168 | 25,256 | 95.5 |
| Maine | 4,395 | 18,903 | 19,066 | 99.1 |
| Maryland | 7,175 | 5,077 | 5,173 | 98.1 |
| Massachusetts | 3,574 | 3,709 | 3,839 | 96.5 |
| Michigan | 21,849 | 29,496 | 30,265 | 97.4 |
| Minnesota | 34,363 | 43,977 | 45,036 | 97.6 |
| Mississippi | 17,630 | 26,688 | 27,063 | 98.6 |
| Missouri | 26,889 | 38,713 | 39,543 | 97.9 |
| Montana | 13,931 | 62,706 | 64,665 | 96.9 |
| Nebraska | 21,481 | 46,624 | 46,990 | 99.2 |
| Nevada | 6,233 | 9,530 | 9,788 | 97.3 |
| New Hampshire | 3,798 | 4,551 | 4,629 | 98.3 |
| New Jersey | 3,846 | 3,226 | 3,342 | 96.4 |
| New Mexico | 9,610 | 46,346 | 50,535 | 91.0 |
| New York | 16,854 | 26,557 | 27,386 | 96.9 |
| North Carolina | 14,875 | 25,741 | 26,481 | 97.1 |
| North Dakota | 19,733 | 40,223 | 41,021 | 98.0 |
| Ohio | 17,293 | 22,005 | 22,859 | 96.1 |
| Oklahoma | 20,822 | 37,940 | 40,795 | 92.5 |
| Oregon | 9,877 | 26,329 | 28,291 | 92.5 |
| Pennsylvania | 24,094 | 24,649 | 25,144 | 98.0 |
| Rhode Island | 1,134 | 497 | 508 | 97.8 |
| South Carolina | 19,495 | 16,278 | 16,681 | 97.5 |
| South Dakota | 19,232 | 42,874 | 44,506 | 96.2 |
| Tennessee | 19,320 | 22,843 | 23,189 | 98.5 |
| Texas | 63,688 | 154,166 | 157,431 | 97.9 |
| Utah | 5,184 | 15,092 | 16,247 | 92.3 |
| Vermont | 6,366 | 5,291 | 5,377 | 98.4 |
| Virginia | 19,414 | 20,244 | 21,292 | 94.8 |
| Washington | 11,694 | 27,166 | 28,462 | 95.2 |
| West Virginia | 12,591 | 13,512 | 13,722 | 98.4 |
| Wisconsin | 17,600 | 30,068 | 30,890 | 97.3 |
| Wyoming | 8,134 | 31,258 | 32,240 | 96.9 |
| **48 State Total** | 775,055 | 1,361,437 | 1,408,401 | 96.6 |

**Figure B–3** Number of mapping polygons per family in the cartographic data base

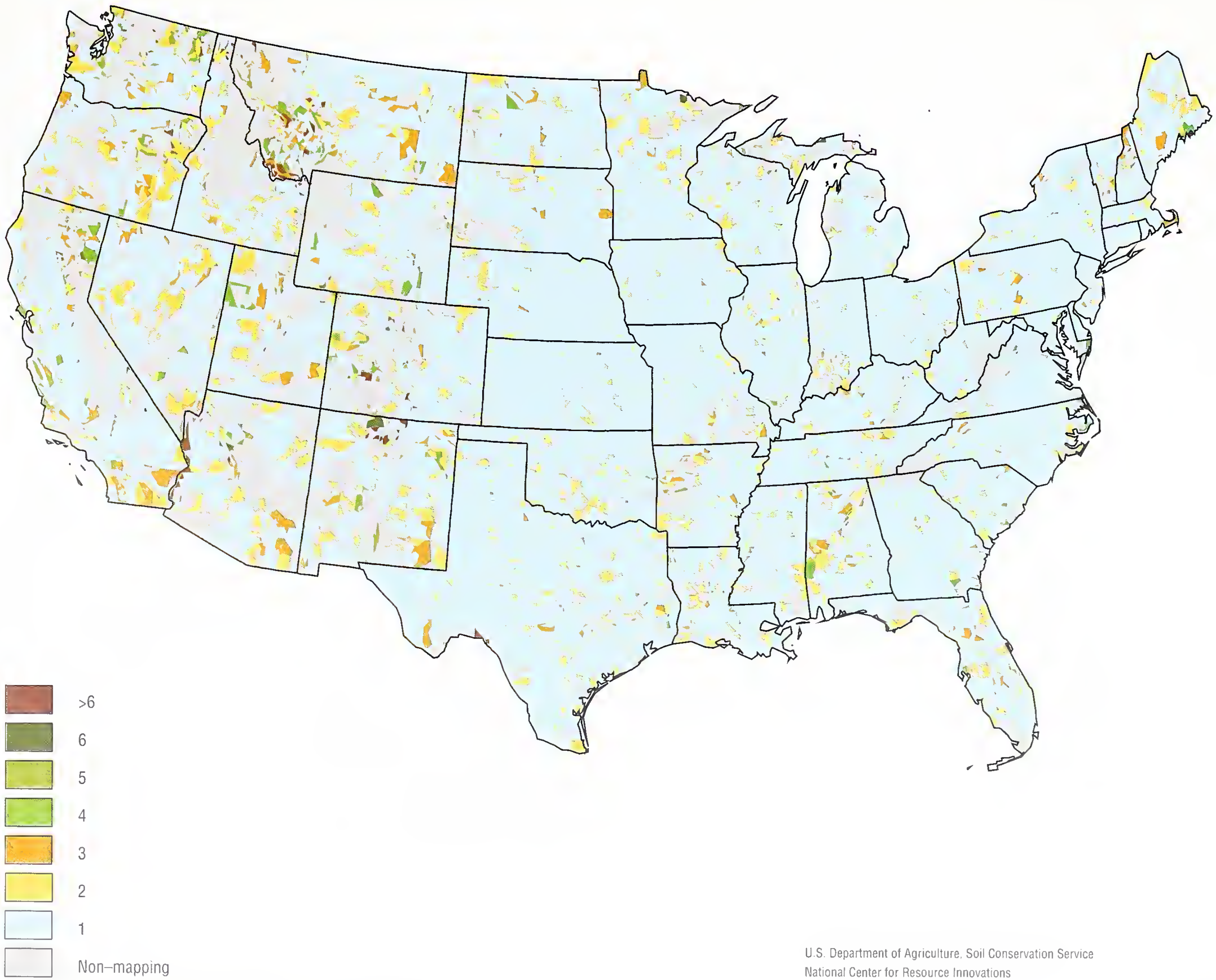


**Figure B–4** Number of NRI sample points per mapping polygon

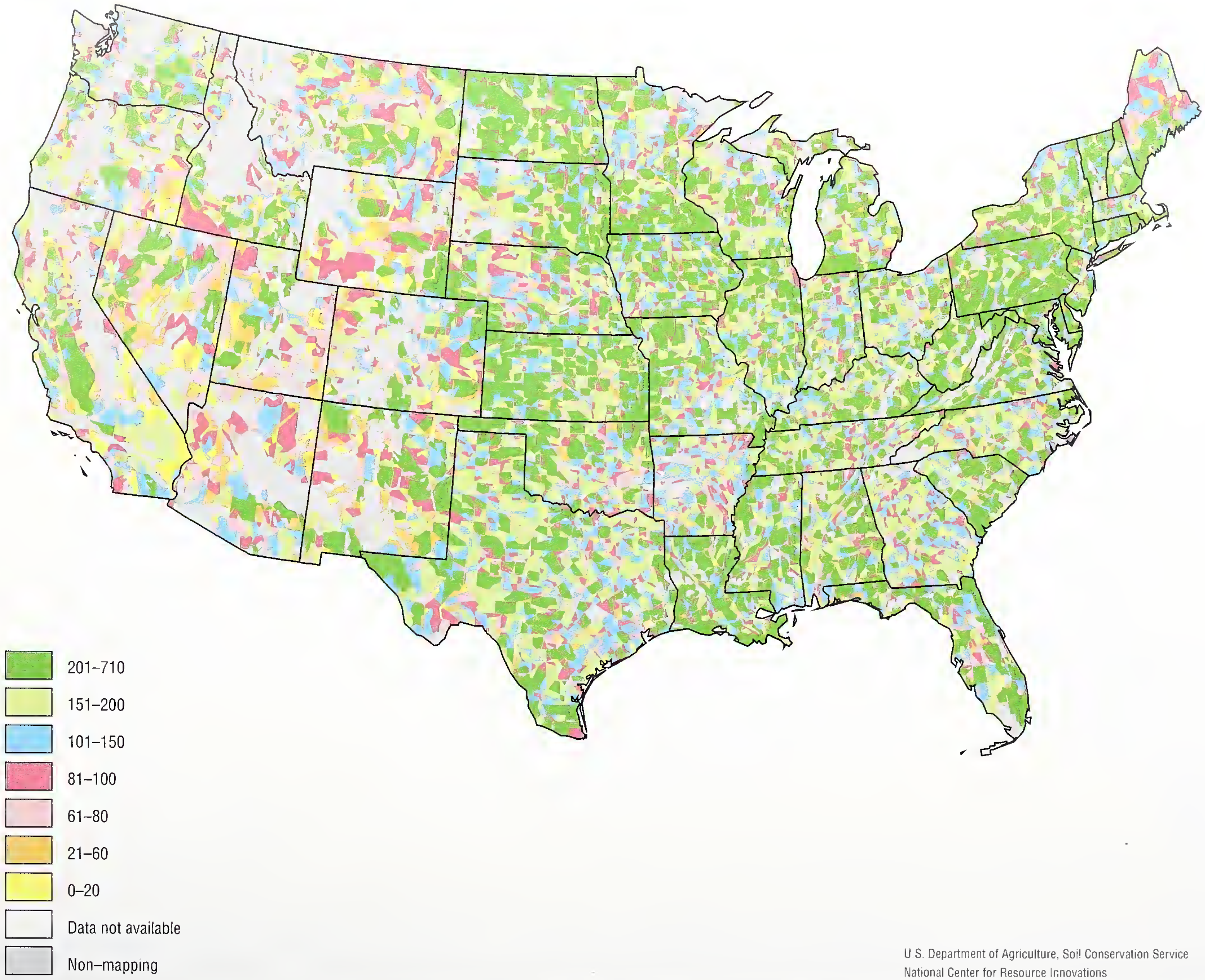


**Figure B–5** Density of NRI sample points (number per 10,000 acres)

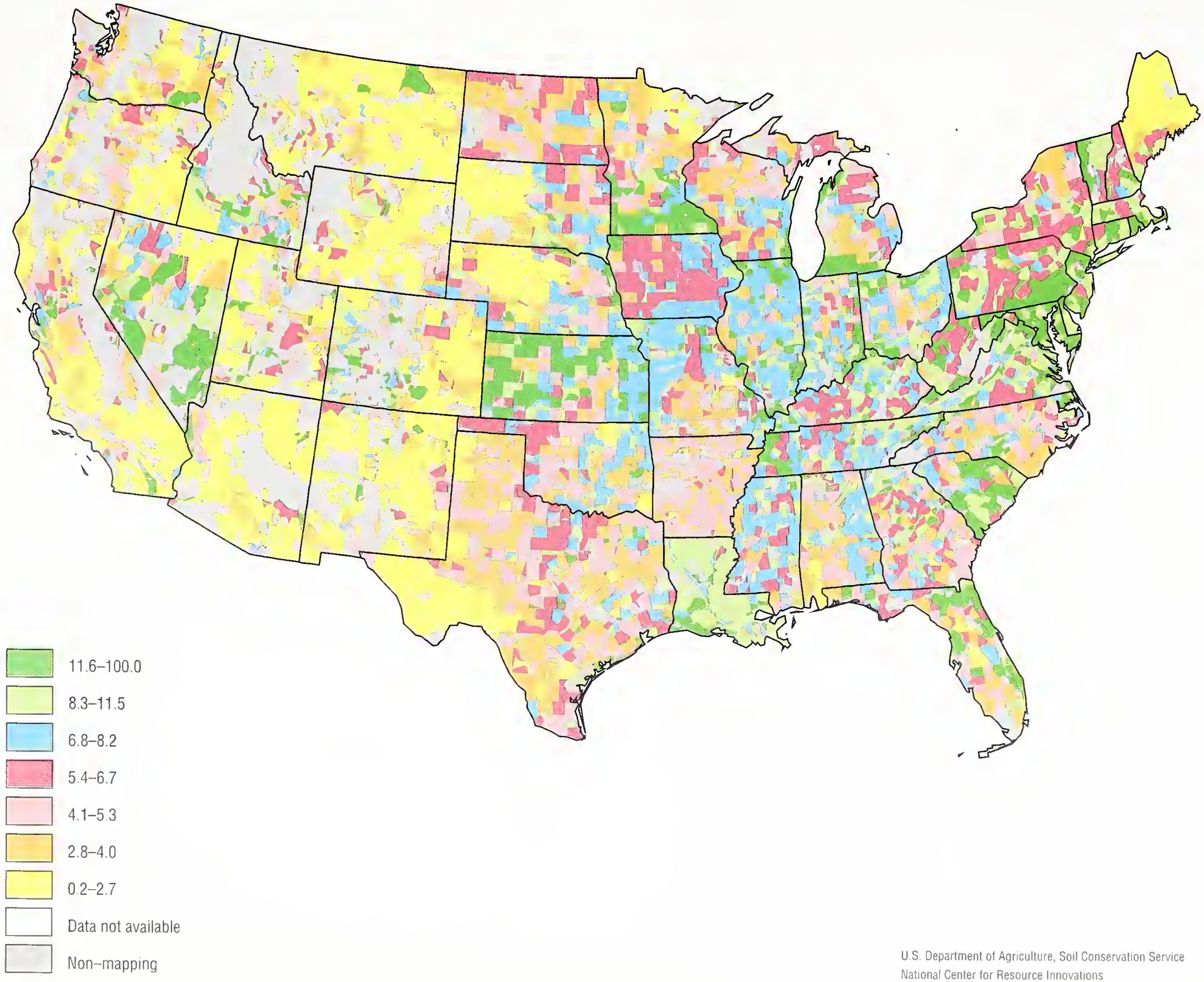
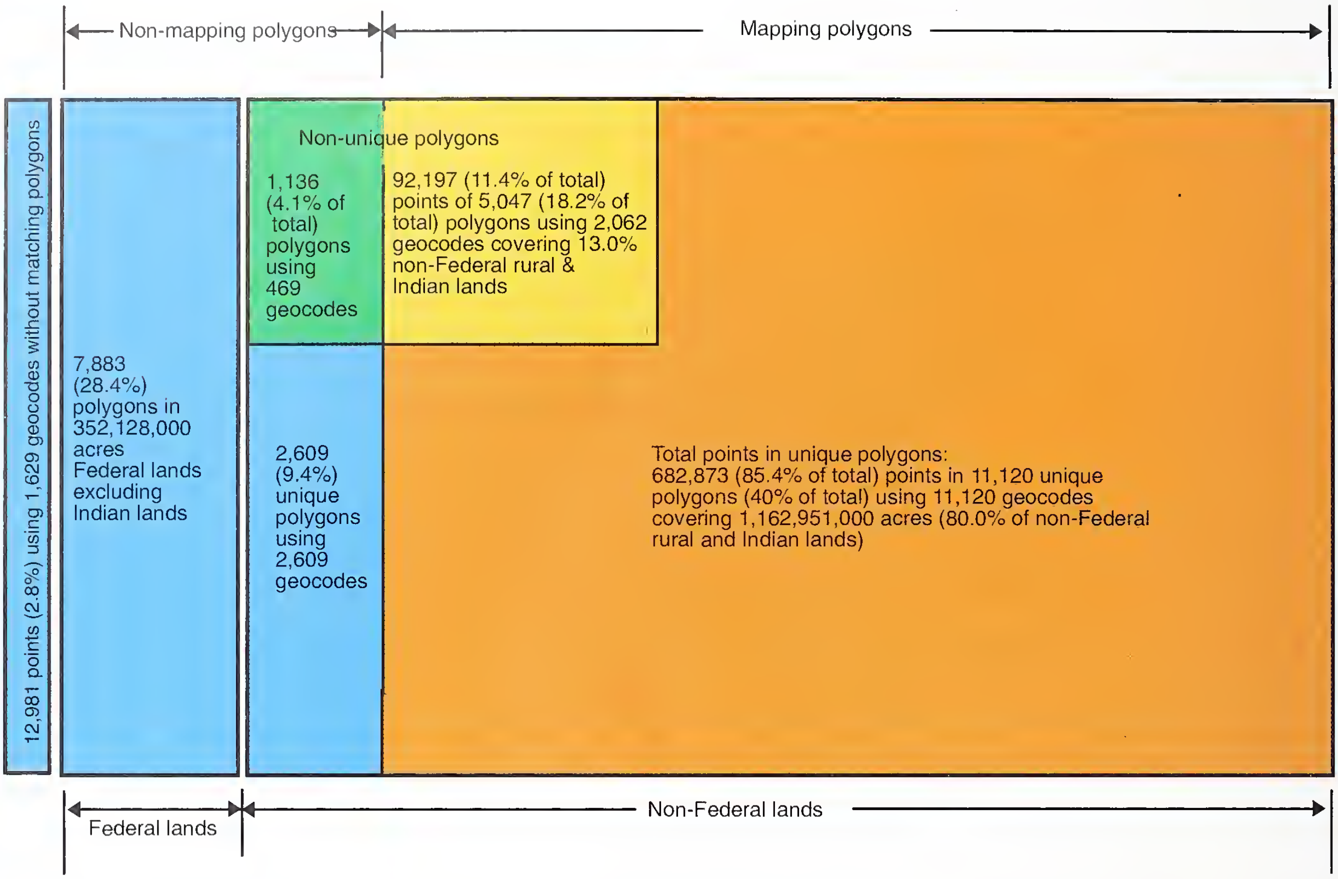


**Figure B–6** Allocation of NRI sample points to NRI polygons




Total number of NRI points is 797,051 using 14,810 geocodes.

Total number of polygons in NRI map base is 27,795 using 18,530 geocodes.

Total number of non-mapping polygons is 3,745 (13.5%) using 3,078 geocodes without points, which include 100,435,000 non-Federal rural acres (7%).

Total number of points in map base is 775,070 (97.2%) matching 16,167 (87.1%) polygons using 13,172 geocodes and includes 1,361,437,000 acres.

# Appendix C: The SCS Soil-Pesticide Interaction Screening Procedure: A National Perspective

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The Soil-Pesticide Interaction Screening Procedure (SPISP) is a first tier procedure developed for the Soil Conservation Service (SCS). The SPISP evaluates the relative loss of pesticides from a field. Screening results are a potential for a specific pesticide loss when applied to an identified soil series. The procedure requires a soils data base and a Pesticide Selected Properties Data Base (PSPD). The PSPD and SPISP were presented by Goss and Wauchope.[1] The PSPD was developed by Wauchope and others.[2] The soils data base was developed by the Soil Conservation Service.

This paper presents the basics on development of the SPISP and the geographical distribution of the soil parameters used to rank the class for soils to leach.

## Screening Procedure Development

### Boundary of consideration

A pesticide is assumed lost if it leaches below the root. Thus, the boundary of consideration is the bottom of the root zone.

### Factors considered in pesticide loss potential

The potential of leaching pesticides is a combined function of pesticide, application, soil, climate, and management factors. The pesticide leaching assessments listed in this paper were developed by using a combination of soil and pesticide properties.

### Soil parameters

Only a few basic soil properties were chosen to represent a wide range of soils. The properties chosen were those that are known to affect pesticide movement. The key soil factors were:

- surface layer thickness,
- surface layer organic matter content,
- surface layer texture,
- subsurface layer texture, and
- hydrologic soil group.

The hypothetical soils had two layers totaling 36 inches in depth, with an upper layer thickness of 6, 10, or 14 inches. The texture of each layer varied, but the lower layer did not have a finer texture than that of the upper layer (table C–1). The hydrologic soil group and effective hydraulic conductivity used in the GLEAMS[3] model was based on the upper and lower layer texture (table C–1).

The organic matter content for layer 1 was 0.5, 1.5, 2.5, and 4.5 percent. The organic matter content for layer 2 was 0.01 percent. The textural properties were estimated from the textural class, and other physical properties were then estimated (table C–2). The estimated soil factors were derived by methods or values given in CREAMS.[4] These values also apply to GLEAMS. The properties estimated from CREAMS are:

1. Effective saturated conductivity from texture and hydrologic soil group using table A-6, page A-8. (Fallow)

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[1] Goss, Don W., and Don Wauchope. "The SCS/ARS/CES Pesticide Properties Database: II, Using it With Soils Data in a Screening Procedure." *in* Pesticides in the Next Decade: The Challenges Ahead, Diana L. Weigman, ed. Virginia Water Resources Research Center, Blacksburg, VA, 1990. pp. 471-493.

[2] Wauchope, R. Don, Arthur G. Hornsby, Don W. Goss, and John P. Burt. "The SCS/ARS/CES pesticide properties database: I, A Set of Parameter Values for First-Tier Comparative Water Pollution Risk Analysis." *in* Pesticides in the Next Decade: The Challenges Ahead, Diana L. Weigman, ed. Virginia Water Resources Research Center, Blacksburg, VA, 1990. pp. 455-470.

[3] Leonard, R.A., W.G. Knisel, and D.A. Still. GLEAMS: Ground Water Loading Effects of Agricultural Management Systems. Transactions of the ASAE, vol. 30, number 5, pp. 1,403–1,418, 1987.

[4] United States Department Agriculture, Soil Conservation Service. User's Guide for the CREAMS Computer Model, Washington Computer Center Version, Technical Release 72, 1984.

2. SCS curve number from hydrologic soil group using table A-4, page A-5. (1) (Fallow, straight row)
3. Field capacity from texture using table A-3, page A-4.
4. Wilting point from texture using table A-3, page A-4.
5. Soil evaporation parameter (not in Table C-2). using table A-3, page A-4.
6. Percentage sand, silt, and clay from texture using table B-4, page B-3.

Properties estimated by other measures are:

1. Bulk density from texture by a method used at the National Soil Survey Laboratory (NSSL), Lincoln, Nebraska. The NSSL method utilizes a large data base for predicting the most probable bulk density from texture.
2. Porosity from [1 - (bulk density)/2.65]*100, a standard calculation.

### Field characteristics

The field was square, 10 acres in size, and had a 4 percent smooth slope. Channel flow and impoundment were not defined. The field was fallow, disked with 10 percent mulch cover.

### Pesticide parameters

The pesticide parameters chosen were solubility, soil half-life, and the organic carbon partitioning coefficient ($K_{oc}$). The values for half-life were 1, 2, 4, and 40 days. The solubility values were 0.1, 1.0, 10.0, 1000, 10000, and 100000 ppm. The $K_{oc}$ was 100, 300, 500, 700, 10000, and 100000 μl/gr. The pesticide was applied to the surface of a bare soil at a rate of 4 kg/ha.

Almost all possible combinations of the soil and pesticide parameters listed above were evaluated with GLEAMS. The total number of combinations examined was 40,896. The GLEAMS estimated annual quantity of pesticide leaching below the root zone was retained for use in development of the algorithms.

## Development of the Algorithms

### Method

A stepwise regression using SAS selected the soil or pesticide input parameters that weighted most heavily for estimating pesticide leaching loss from the GLEAMS runs. Pesticide loss was placed into four classes for each of the soil and pesticide input parameter sets by using their respective parameters in algo-

**Table C–1** Effective hydrologic conductivity (in/hr) by soil textural class and hydrologic group

| Texture | | Soil Hydrologic Group | | | |
|---|---|---|---|---|---|
| Horizon 1 | Horizon 2 | A | B | C | D |
| Sand | Sand | 0.45 | — | — | — |
| | Sandy Loam | 0.42 | 0.30 | — | — |
| | Silt Loam | — | 0.25 | 0.15 | — |
| | Clay Loam | — | — | 0.10 | 0.03 |
| | Clay | — | — | — | 0.02 |
| Sandy Loam | Sandy Loam | 0.42 | 0.30 | — | — |
| | Silt Loam | — | 0.25 | 0.15 | — |
| | Clay Loam | — | — | 0.10 | 0.03 |
| | Clay | — | — | — | 0.02 |
| Silt Loam | Silt Loam | — | 0.25 | 0.15 | — |
| | Clay Loam | — | — | 0.10 | 0.03 |
| | Clay | — | — | — | 0.02 |
| Clay Loam | Clay Loam | — | — | 0.10 | 0.03 |
| | Clay | — | — | — | 0.02 |
| Clay | Clay | — | — | — | 0.02 |

**Table C-2** Textural and related properties of soils used in GLEAMS runs

| Texture | Sand<br>% | Silt<br>% | Clay<br>% | Porosity<br>cm/cm | Bulk density<br>gr/cc | Field capacity<br>cm/cm | Wilting point<br>cm/cm |
|---|---|---|---|---|---|---|---|
| Sand | 80 | 15 | 5 | 0.41 | 1.55 | 0.16 | 0.03 |
| Sandy Loam | 60 | 25 | 15 | 0.41 | 1.55 | 0.22 | 0.04 |
| Silt Loam | 15 | 60 | 25 | 0.51 | 1.28 | 0.32 | 0.07 |
| Clay Loam | 30 | 35 | 35 | 0.45 | 1.45 | 0.35 | 0.10 |
| Clay | 20 | 25 | 55 | 0.48 | 1.38 | 0.39 | 0.33 |

rithms. Mostly a trial-and-error procedure was used for selecting the algorithm and setting algorithm break points to separate each rank. The loss ranks were combined in a matrix using the four soil loss ranks as rows and the four pesticide loss ranks as columns. The maximum values for each column and row intersection in the matrix were examined to see if they fell within the pre-established limits for a potential. If the pre-established limits failed, the algorithm was adjusted, new statistical parameters calculated, and the comparisons made again.

### Establishing limits for potentials

The upper limit of loss for *Potential 4* was set at zero. The upper limit for *Potential 3* was the smallest value estimated by GLEAMS for pesticides that were known to contaminate ground water from a nonpoint source. This value was 600 gr/ha for this particular set of GLEAMS runs. The upper limit for *Potential 2* was arbitrarily set at three times the value of the upper limit of potential three (1,800 gr/ha). *Potential 1* did not have an upper limit, but would be 4,000 gr/ha for this set of GLEAMS runs. The objective of the matrix groupings was to refine the algorithms so that each maximum loss potential was not greater than the limits established.

### Soil algorithm

The algorithms for soil classes (table C–3) are complex. The parameters in the algorithms were chosen to equate to parameters in the SCS Soil Interpretation Record Data Base. The parameters are soil hydrologic group, K factor, and organic matter content.

Hydrologic group is a soil interpretation used by the SCS to categorize soils into their potential to infiltrate water. Other factors relating to water movement in soil may have provided a better discriminator, but are not available in the SCS data base.

The SCS defines the soil erodibility factor (K) as a measure of the susceptibility of a soil to particle detachment and transport by rainfall. Soil properties that influence the K factor are those that affect infiltration, movement of water through the soil, and water storage capacity. It is a quantitative value, experimentally determined. The 14 classes of K values are 0.02, 0.05, 0.10, 0.15, 0.17, 0.20, 0.24, 0.28, 0.32, 0.37, 0.43, 0.49, 0.55, and 0.64 and greater. The K factor is used in the algorithm to provide soil-water movement information not furnished by hydrologic soil group.

The combined factors of organic matter times layer #1 depth is a simple method of estimating the total mass of organic carbon available to adsorbed pesticides. The SCS Soil Interpretation Record does not generally have organic matter content for horizons other than the surface layer. Organic carbon is an estimated parameter in the SCS data base. Ranges are used for this value that may vary by as much as 6 percentage points. The mid value of the range was used to estimate the soil leaching class.

### Pesticide algorithm

The algorithm using pesticide input parameters (table C–4) resulted in a pesticide leaching algorithm very similar to the Groundwater Ubiquity Score (GUS) by Gustafson.[5] The GUS was chosen as the algorithm to use because that work contained additional verification not planned for this procedure. The pesticide parameters chosen were the $K_{oc}$, half-life, and solubility.

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[5] Gustafson, D.I., Ground Water Ubiquity Score: A Simple Method for Accessing Pesticide Leachability. Environmental Toxicology and Chemistry. 8:339-357

**Table C–3** Soil leaching class algorithm

| | |
|---|---|
| **High:** | If hydrologic group = A & organic carbon times layer #1 depth <= 30 or<br>If hydrologic group = B and organic carbon times layer #1 depth <=9 & Soil K factor <= .49 or<br>If hydrologic group = B and organic carbon times layer #1 depth <= 15 and Soil K factor <= 28 |
| **Low:** | If hydrologic group = B or C and organic carbon times layer #1 depth > 100 or<br>If hydrologic group = B and organic carbon times layer #1 depth >= 35 and Soil K factor >= .43 or<br>If hydrologic group = B and organic carbon times layer #1 depth >=45 and Soil K factor >= .20 or<br>If hydrologic group = C and organic carbon times layer #1 depth <= 10 and Soil K factor >= .28 or<br>If hydrologic group = C and organic carbon times layer #1 depth >= 10 |
| **Very Low:** | If hydrologic group = D. (Note: Cracking soils may have a low or intermediate class when dry.) |
| **Intermediate:** | Everything else |

The solubility of a pesticide is a measure of the amount of pesticide that goes into solution. The $K_{oc}$ is a measure of the amount of pesticide that can be adsorbed by organic carbon. The half-life is a measure of the number of days required for a pesticide to degrade to one-half the original mass.

The leaching class for soils and pesticides does not have an absolute definition relative to quantity. Pesticide losses from this model reflect only the relative ability of the soil to retain the pesticide at the point of application. The interplay of climate, application method, and cultivation determines whether the leaching loss classes are reached in a given area. The relative position of a soil or pesticide in a leaching class remains about the same as precipitation is varied.

## Classification Results

The statistical parameters maximum, minimum, mean, and standard deviation for each matrix cell (table C–5) indicate integrity of the final classification scheme. These values are relative. The units of gr/ha reflect the results of GLEAMS.

The group integrity can be determined by comparing statistical table C–5 with the potential given in table C–6. These comparisons indicate *Potential 4* does not contain losses that are over 2.0 gr/ha, where the predetermined upper limit was 0.0 gr/ha. *Potential 3* does not contain losses over 589 gr/ha where the predetermined upper limit was 600 gr/ha. *Potential 2*, with a predetermined upper limit of 1,800 gr/ha, does not contain losses over 1,508 gr/ha. Examining the minimum values in table C–5 shows that all potentials can contain members of a potential that is less likely to leach.

**Table C–4** Pesticide leaching class algorithm after Gustafson

| | |
|---|---|
| Large | If log(half-life)*(4 - log($K_{oc}$)) >= 2.8 |
| Small | If log(half-life)*(4 - log($K_{oc}$)) <= 1.8 |
| Extra small | If log(half-life)*(4 - log($K_{oc}$)) < 0.0 or Solubility < 1 & half-life <= 1 |
| Medium | Everything else |

## Definition of Loss Potential

The potential pesticide loss is relative and explains no more than a relative expectation of pesticide loss when applied to an identified soil series. A *Potential 1* has a higher expectation of leaching below the root zone than *Potential 2*, and *Potential 2* has a higher expectation than *Potential 3*. *Potential 4* has essentially a zero expectation of having the pesticide leach below the root zone. Because *Potentials 1* and *2* contain some occurrences of loss that are low, the use of this information in large scale categorization schemes is biased toward having a pesticide loss. The principle concept of the scheme was to have a high degree of confidence in estimating soil-pesticide interactions that will *not* leach. *Potentials 3* and *4* do not contain occurrences of loss that are high, which supports the principle concept.

## Spatial Distribution of Soils Parameters

The soils components used in the SPISP that can be mapped are soil K factor, organic matter content, and hydrologic soil group. The cartographic data base used to map these NRI attributes is discussed in appendix B.

The area weighted average soil K factor for each polygon in the cartographic data base is shown in figure C–1, and the distribution by State is shown in table C–7.

**Table C–5** Statistics, potential pesticide loss to leaching using GUS

| Soil leach class | ---- Pesticide leaching class (gr/ha) ---- Large | Medium | Small | Extra small | Stats. |
|---|---|---|---|---|---|
| High | 3,469 | 3,159 | 1,508 | 29 | Max |
| | 132 | 14 | 0 | 0 | Min |
| | 2,018 | 1,012 | 74 | 0.4 | Mean |
| | 898 | 732 | 162 | 1.9 | Std dev |
| Intermediate | 2,266 | 1,185 | 319 | 2 | Max |
| | 29 | 0 | 0 | 0 | Min |
| | 1,054 | 227 | 9 | 0 | Mean |
| | 578 | 228 | 30 | 0.2 | Std dev |
| Low | 877 | 589 | 47 | 0.1 | Max |
| | 0 | 0 | 0 | 0 | Min |
| | 189 | 35 | 0.2 | 0 | Mean |
| | 227 | 70 | 1.6 | 0 | Std dev |
| Very low | 83 | 39 | 0 | 0 | Max |
| | 0 | 0 | 0 | 0 | Min |
| | 7 | 1 | 0 | 0 | Mean |
| | 15 | 4 | 0 | 0 | Std dev |

The average percent organic matter weighted by the uppermost layer thickness is shown in figure C–2. This value is calculated by multiplying the percent organic matter by the layer thickness, and the area weighted average of this value is calculated for each mapping polygon.

$$\frac{\sum_{i=1}^{N} OC_i \times T_i \times EXPAND_i}{\sum_{i=1}^{N} EXPAND_i}$$

where:

$N$ = number of NRI points in polygon
$OC_i$ = organic carbon content of layer 1 at NRI point i
$EXPAND_i$ = expansion value at NRI point i
$T_i$ = thickness of layer 1 at NRI point i

The distribution by State of the depth-weighted percent organic carbon in the soil surface horizon is presented in table C–8.

The spatial distributions of the four hydrologic soil groups are shown in figures C–3 through C–6. The mapped value is the area-weighted percentage of the soil hydrologic group for each mapping polygon, calculated as described in appendix B.

The algorithms that determine the soil leaching classes describe the complex interaction between each soil component. Soil leaching class distribution is difficult to determine by examining the distribution of a single soil component. The exception is soil hydrologic group D, which maps exclusively to the *Very Low Soil Leaching Class*. The National distribution of soils in the four soil leaching classes are shown in figures 1 through 4 of this publication.

**Table C–6** Potential pesticide loss to leaching screening matrix

| Soil leaching class | ----- Pesticide leaching class ----- Large | Medium | Small | Extra small |
|---|---|---|---|---|
| High | 1 | 1 | 2 | 3 |
| Intermediate | 1 | 2 | 3 | 4 |
| Low | 2 | 3 | 3 | 4 |
| Very low | 3 | 3 | 4 | 4 |

## Spatial Distribution of Pesticide Loss Potentials

The pesticide loss potential can be estimated for each NRI sample point when pesticide use information is available. Pesticide use data were imputed to the NRI sample points according to procedures presented in appendix E. After ranking the pesticides and soil into leaching classes, the leaching potential can be determined from the matrix in table C–6. Figures C–7 and C–8 show the percent area with soil-pesticide *Potential 1* and *Potential 2*, respectively. These are areas that may leach through the soil. Figure C–9 shows the percent area with soil-pesticide *Potentials 3* or *4*. These are the potentials considered not to leach through the soil. The percent area calculations shown in figures C–7 through C–9 are based on *cropland* acres only.

NRI sample points that have crops where more than one pesticide is used may have more than one pesticide loss potential. For example, suppose an NRI sample point with a soil that is classed as Intermediate had two pesticides applied to the crop grown at that point, one in the *Large Pesticide Leaching Class* and the other in the *Small Pesticide Leaching Class*. In this case, the sample point would have two potentials, *Potential 1* and *Potential 3*. Consequently, figures C–7 through C–9 are not mutually exclusive.

**Table C–7** K factor distribution (percent) by State

| | .02 and .05 | .1 and .15 | .17 and .2 | .24 and .28 | .32 and .37 | .43 and .49 | .55 and over |
|---|---|---|---|---|---|---|---|
| Alabama | 0.0 | 15.0 | 18.7 | 46.8 | 16.5 | 2.9 | 0.0 |
| Arizona | 7.3 | 24.9 | 25.0 | 25.8 | 11.9 | 4.1 | 1.0 |
| Arkansas | 0.0 | 3.7 | 8.9 | 26.9 | 29.8 | 30.7 | 0.0 |
| California | 0.4 | 13.3 | 17.0 | 24.2 | 36.2 | 8.7 | 0.2 |
| Colorado | 1.1 | 18.8 | 21.6 | 22.7 | 30.5 | 5.3 | 0.0 |
| Connecticut | 0.2 | 0.0 | 68.0 | 25.0 | 2.9 | 4.0 | 0.0 |
| Delaware | 0.5 | 3.4 | 40.1 | 34.5 | 11.9 | 9.6 | 0.0 |
| Florida | 0.1 | 90.1 | 4.9 | 2.9 | 2.0 | 0.0 | 0.0 |
| Georgia | 0.0 | 46.4 | 12.6 | 34.9 | 4.8 | 1.3 | 0.0 |
| Idaho | 0.5 | 8.7 | 12.6 | 18.1 | 30.5 | 28.3 | 1.3 |
| Illinois | 0.0 | 0.6 | 3.1 | 39.5 | 43.9 | 13.0 | 0.0 |
| Indiana | 0.2 | 1.8 | 7.4 | 26.6 | 38.2 | 25.8 | 0.0 |
| Iowa | 0.0 | 0.3 | 2.2 | 60.6 | 35.7 | 1.2 | 0.0 |
| Kansas | 0.0 | 0.9 | 9.3 | 14.4 | 65.2 | 10.2 | 0.0 |
| Kentucky | 0.0 | 0.4 | 8.9 | 15.6 | 45.3 | 29.7 | 0.0 |
| Louisiana | 0.0 | 1.8 | 3.2 | 18.3 | 29.6 | 47.2 | 0.0 |
| Maine | 0.1 | 4.5 | 45.4 | 41.9 | 6.7 | 1.4 | 0.0 |
| Maryland | 0.2 | 6.5 | 12.8 | 29.8 | 32.3 | 18.4 | 0.0 |
| Massachusetts | 1.4 | 4.4 | 70.3 | 18.8 | 2.3 | 2.7 | 0.1 |
| Michigan | 0.1 | 24.2 | 25.6 | 30.2 | 17.1 | 2.9 | 0.0 |
| Minnesota | 0.0 | 5.5 | 14.7 | 58.4 | 20.5 | 0.9 | 0.0 |
| Mississippi | 0.0 | 1.7 | 6.2 | 31.6 | 29.6 | 29.7 | 1.3 |
| Missouri | 0.0 | 0.3 | 3.6 | 37.0 | 42.3 | 16.8 | 0.0 |
| Montana | 0.3 | 4.2 | 19.0 | 5.8 | 58.5 | 12.1 | 0.0 |
| Nebraska | 0.0 | 25.0 | 14.1 | 12.8 | 40.0 | 8.2 | 0.0 |
| Nevada | 4.1 | 17.8 | 16.7 | 18.1 | 18.5 | 16.0 | 8.8 |
| New Hampshire | 0.2 | 7.7 | 59.6 | 26.1 | 1.6 | 4.9 | 0.0 |
| New Jersey | 0.4 | 4.2 | 44.3 | 20.9 | 18.5 | 11.8 | 0.0 |
| New Mexico | 0.4 | 17.8 | 18.6 | 24.2 | 30.1 | 7.2 | 1.7 |
| New York | 0.1 | 0.9 | 33.0 | 36.6 | 17.1 | 12.4 | 0.0 |
| North Carolina | 0.2 | 19.6 | 25.9 | 38.3 | 9.3 | 6.7 | 0.0 |
| North Dakota | 0.1 | 0.7 | 12.2 | 61.5 | 25.4 | 0.2 | 0.0 |
| Ohio | 0.1 | 0.2 | 3.7 | 22.4 | 44.1 | 29.5 | 0.0 |
| Oklahoma | 0.0 | 3.2 | 21.2 | 17.6 | 41.0 | 16.9 | 0.0 |
| Oregon | 0.8 | 23.1 | 22.4 | 17.5 | 23.5 | 11.4 | 1.2 |
| Pennsylvania | 0.0 | 7.5 | 23.5 | 35.6 | 24.7 | 8.6 | 0.0 |
| Rhode Island | 1.2 | 0.3 | 72.1 | 18.3 | 0.9 | 7.1 | 0.0 |
| South Carolina | 0.0 | 32.1 | 19.0 | 39.6 | 4.9 | 4.3 | 0.0 |
| South Dakota | 0.1 | 1.9 | 6.9 | 37.8 | 48.9 | 3.5 | 0.9 |
| Tennessee | 0.0 | 0.6 | 12.3 | 34.9 | 23.7 | 28.5 | 0.0 |
| Texas | 0.1 | 18.5 | 14.4 | 18.6 | 40.3 | 7.9 | 0.2 |
| Utah | 5.8 | 18.1 | 15.9 | 18.2 | 24.6 | 15.6 | 1.8 |
| Vermont | 0.0 | 0.3 | 31.2 | 36.9 | 12.2 | 19.4 | 0.0 |
| Virginia | 0.1 | 4.4 | 18.3 | 45.0 | 25.9 | 6.4 | 0.0 |
| Washington | 0.5 | 15.7 | 15.0 | 18.2 | 24.3 | 17.2 | 9.0 |
| West Virginia | 0.0 | 4.5 | 22.7 | 27.1 | 40.0 | 5.7 | 0.0 |
| Wisconsin | 0.0 | 5.6 | 17.2 | 26.7 | 48.9 | 1.5 | 0.0 |
| Wyoming | 1.9 | 12.6 | 13.8 | 22.9 | 43.9 | 4.8 | 0.2 |
| **48 State Total** | 0.5 | 12.3 | 15.5 | 27.7 | 32.8 | 10.7 | 0.5 |

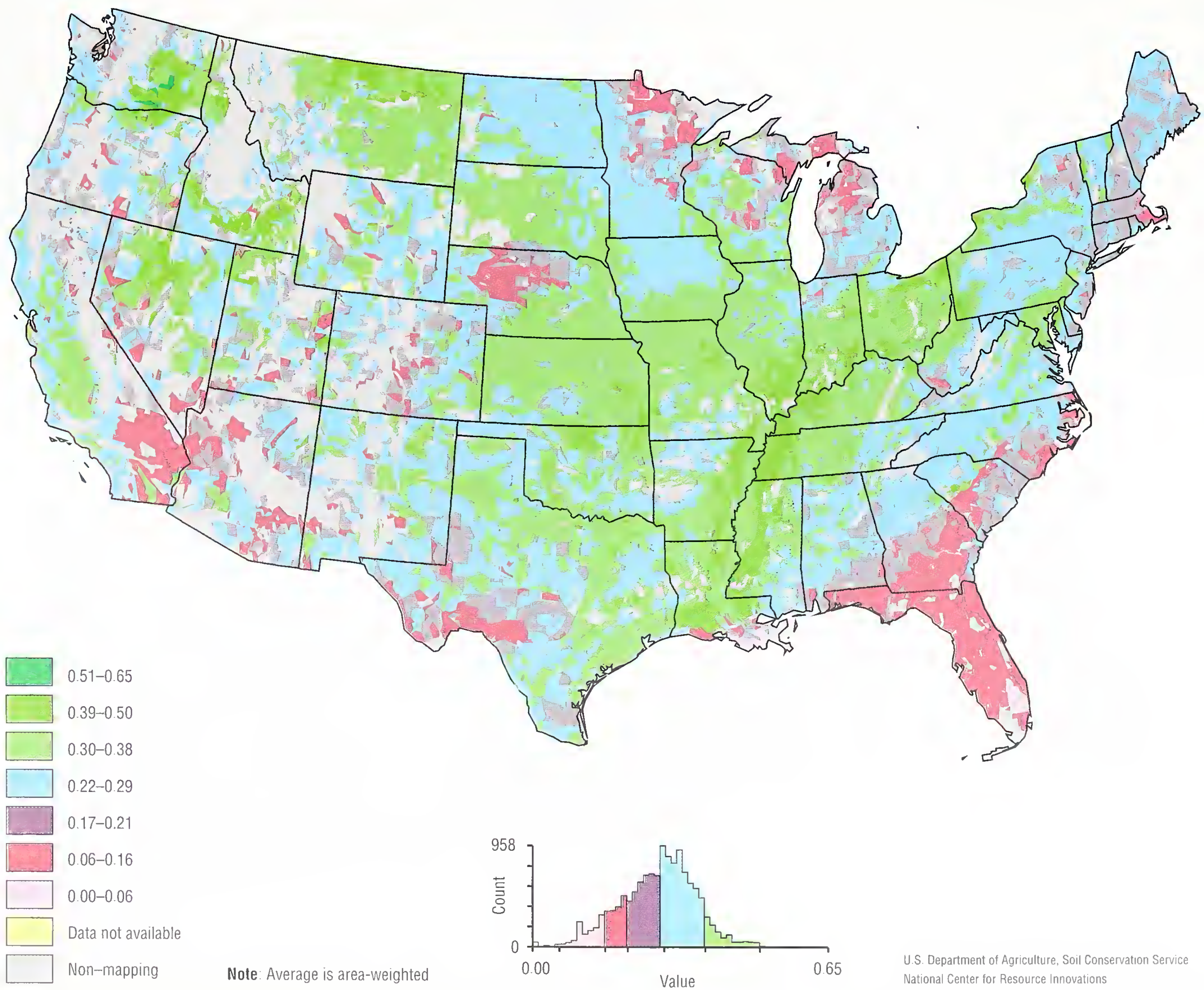
**Table C–8** Percent area of depth-weighted percent organic carbon in soil surface horizon

| | 0 to 5 | 5 to 10 | 10 to 20 | 20 to 40 | 40 to 60 | 60 to 100 | > 100 |
|---|---|---|---|---|---|---|---|
| Alabama | 12.5 | 36.3 | 31.7 | 17.0 | 0.8 | 0.8 | 0.8 |
| Arizona | 66.3 | 16.9 | 12.6 | 3.3 | 0.4 | 0.0 | 0.5 |
| Arkansas | 11.4 | 30.0 | 38.9 | 17.0 | 1.7 | 0.9 | 0.2 |
| California | 28.1 | 16.6 | 19.8 | 19.5 | 7.9 | 5.9 | 2.2 |
| Colorado | 35.6 | 17.2 | 27.3 | 15.8 | 2.3 | 1.2 | 0.5 |
| Connecticut | 54.1 | 6.9 | 0.5 | 30.3 | 2.4 | 1.5 | 4.3 |
| Delaware | 1.2 | 0.3 | 65.7 | 10.2 | 10.3 | 1.1 | 11.2 |
| Florida | 7.8 | 17.3 | 13.3 | 22.2 | 9.2 | 8.2 | 22.1 |
| Georgia | 18.7 | 28.7 | 19.0 | 15.2 | 12.0 | 2.7 | 3.8 |
| Idaho | 11.2 | 11.1 | 31.0 | 27.0 | 9.5 | 7.1 | 3.1 |
| Illinois | 2.3 | 9.2 | 23.8 | 18.4 | 21.2 | 22.0 | 3.0 |
| Indiana | 1.8 | 9.3 | 34.2 | 31.8 | 10.3 | 10.8 | 1.9 |
| Iowa | 0.8 | 1.5 | 9.7 | 25.8 | 21.5 | 23.1 | 17.7 |
| Kansas | 5.0 | 7.6 | 32.9 | 43.7 | 7.8 | 1.7 | 1.3 |
| Kentucky | 4.3 | 11.0 | 40.3 | 38.6 | 3.6 | 1.9 | 0.4 |
| Louisiana | 6.5 | 11.7 | 35.1 | 26.1 | 9.9 | 0.6 | 10.1 |
| Maine | 49.3 | 0.3 | 19.3 | 14.5 | 8.8 | 4.3 | 3.6 |
| Maryland | 4.8 | 2.7 | 59.0 | 24.0 | 3.1 | 0.5 | 5.9 |
| Massachusetts | 45.9 | 10.1 | 6.2 | 23.6 | 6.2 | 1.4 | 6.7 |
| Michigan | 4.5 | 14.4 | 25.6 | 35.1 | 4.9 | 4.2 | 11.2 |
| Minnesota | 6.3 | 6.5 | 15.0 | 19.7 | 12.1 | 16.5 | 23.9 |
| Mississippi | 10.5 | 26.1 | 47.9 | 13.0 | 0.6 | 1.3 | 0.6 |
| Missouri | 2.6 | 19.0 | 38.7 | 28.5 | 5.9 | 3.7 | 1.5 |
| Montana | 10.6 | 36.6 | 32.2 | 17.5 | 2.0 | 0.7 | 0.4 |
| Nebraska | 28.9 | 14.9 | 22.5 | 22.6 | 7.9 | 1.9 | 1.3 |
| Nevada | 41.1 | 18.0 | 21.0 | 16.9 | 2.1 | 0.7 | 0.2 |
| New Hampshire | 54.1 | 7.1 | 6.5 | 15.5 | 8.3 | 1.0 | 7.5 |
| New Jersey | 11.5 | 6.1 | 29.2 | 30.2 | 9.6 | 2.2 | 11.3 |
| New Mexico | 38.3 | 31.7 | 24.1 | 5.7 | 0.2 | 0.0 | 0.0 |
| New York | 12.9 | 1.0 | 14.6 | 46.9 | 17.1 | 4.6 | 3.0 |
| North Carolina | 10.0 | 26.5 | 27.3 | 16.9 | 7.3 | 2.3 | 9.7 |
| North Dakota | 3.1 | 11.8 | 11.0 | 37.5 | 13.4 | 18.0 | 5.1 |
| Ohio | 2.0 | 3.2 | 42.6 | 34.0 | 9.9 | 7.8 | 0.4 |
| Oklahoma | 11.0 | 26.3 | 29.4 | 25.0 | 5.3 | 1.2 | 1.7 |
| Oregon | 8.3 | 11.9 | 31.0 | 21.7 | 12.9 | 8.0 | 6.1 |
| Pennsylvania | 15.6 | 2.5 | 42.9 | 37.6 | 1.1 | 0.3 | 0.1 |
| Rhode Island | 17.2 | 33.9 | 3.1 | 35.8 | 3.1 | 0.0 | 6.9 |
| South Carolina | 10.7 | 26.2 | 22.0 | 23.1 | 8.1 | 2.8 | 7.1 |
| South Dakota | 11.0 | 22.8 | 20.8 | 30.3 | 8.0 | 4.5 | 2.6 |
| Tennessee | 21.5 | 22.6 | 36.3 | 14.1 | 0.9 | 3.9 | 0.7 |
| Texas | 15.3 | 28.1 | 32.3 | 17.0 | 5.0 | 1.8 | 0.5 |
| Utah | 35.1 | 14.6 | 21.0 | 17.0 | 6.5 | 4.2 | 1.5 |
| Vermont | 16.2 | 7.0 | 22.6 | 30.4 | 11.7 | 9.6 | 2.4 |
| Virginia | 8.4 | 25.3 | 46.2 | 17.1 | 2.3 | 0.1 | 0.6 |
| Washington | 8.7 | 6.7 | 39.2 | 19.2 | 8.5 | 10.4 | 7.4 |
| West Virginia | 17.7 | 5.3 | 46.8 | 29.9 | 0.2 | 0.0 | 0.0 |
| Wisconsin | 9.8 | 14.3 | 27.2 | 23.0 | 10.2 | 4.9 | 10.6 |
| Wyoming | 35.7 | 28.4 | 24.6 | 8.3 | 2.2 | 0.8 | 0.1 |
| **48 State Total** | 16.2 | 18.4 | 27.7 | 22.1 | 6.9 | 4.7 | 3.9 |

**Table C–9** Percent area in hydrologic soil groups

| | A | B | C | D |
|---|---|---|---|---|
| Alabama | 10.3 | 38.2 | 27.7 | 23.9 |
| Arizona | 6.6 | 38.8 | 12.0 | 42.6 |
| Arkansas | 0.9 | 27.1 | 35.8 | 36.2 |
| California | 6.8 | 36.0 | 22.8 | 34.5 |
| Colorado | 8.7 | 50.8 | 22.7 | 17.8 |
| Connecticut | 14.5 | 36.4 | 45.0 | 4.0 |
| Delaware | 15.9 | 61.1 | 11.1 | 11.9 |
| Florida | 19.5 | 55.6 | 8.4 | 16.4 |
| Georgia | 10.6 | 59.8 | 17.5 | 12.1 |
| Idaho | 2.4 | 54.4 | 28.1 | 15.1 |
| Illinois | 1.6 | 60.8 | 28.5 | 9.1 |
| Indiana | 5.6 | 46.0 | 45.0 | 3.4 |
| Iowa | 1.4 | 83.2 | 12.7 | 2.8 |
| Kansas | 4.0 | 59.8 | 18.6 | 17.6 |
| Kentucky | 1.1 | 42.1 | 45.2 | 11.5 |
| Louisiana | 1.8 | 15.3 | 24.5 | 58.4 |
| Maine | 7.2 | 14.0 | 55.6 | 23.2 |
| Maryland | 7.0 | 48.2 | 34.1 | 10.7 |
| Massachusetts | 19.2 | 19.6 | 47.1 | 14.1 |
| Michigan | 42.3 | 40.7 | 13.3 | 3.8 |
| Minnesota | 22.0 | 54.6 | 16.7 | 6.7 |
| Mississippi | 1.8 | 32.4 | 37.1 | 28.8 |
| Missouri | 1.2 | 44.7 | 36.9 | 17.2 |
| Montana | 2.5 | 42.9 | 31.3 | 23.2 |
| Nebraska | 33.4 | 53.0 | 3.7 | 9.9 |
| Nevada | 5.8 | 31.5 | 28.7 | 34.0 |
| New Hampshire | 16.4 | 26.9 | 52.1 | 4.6 |
| New Jersey | 12.8 | 41.9 | 30.4 | 14.9 |
| New Mexico | 5.8 | 44.9 | 13.0 | 36.3 |
| New York | 11.0 | 18.7 | 60.0 | 10.3 |
| North Carolina | 7.5 | 54.5 | 20.8 | 17.2 |
| North Dakota | 5.1 | 63.1 | 18.8 | 13.0 |
| Ohio | 1.3 | 24.2 | 61.9 | 12.6 |
| Oklahoma | 7.2 | 48.2 | 22.6 | 21.9 |
| Oregon | 3.8 | 33.7 | 35.2 | 27.3 |
| Pennsylvania | 5.8 | 27.9 | 60.5 | 5.9 |
| Rhode Island | 20.4 | 44.3 | 31.4 | 3.8 |
| South Carolina | 12.8 | 48.9 | 19.2 | 19.0 |
| South Dakota | 3.6 | 46.5 | 14.6 | 35.3 |
| Tennessee | 0.2 | 54.5 | 30.3 | 15.1 |
| Texas | 5.1 | 29.7 | 24.2 | 41.0 |
| Utah | 2.2 | 41.0 | 23.2 | 33.7 |
| Vermont | 6.2 | 21.5 | 56.3 | 16.0 |
| Virginia | 4.2 | 51.8 | 36.3 | 7.8 |
| Washington | 4.5 | 58.6 | 23.2 | 13.7 |
| West Virginia | 10.2 | 20.1 | 58.2 | 11.5 |
| Wisconsin | 24.6 | 53.2 | 16.2 | 6.0 |
| Wyoming | 4.5 | 40.7 | 19.6 | 35.2 |
| **48 State Total** | 8.1 | 43.6 | 26.0 | 22.3 |

**Figure C–1** Average K factor




**Note**: Average is area-weighted

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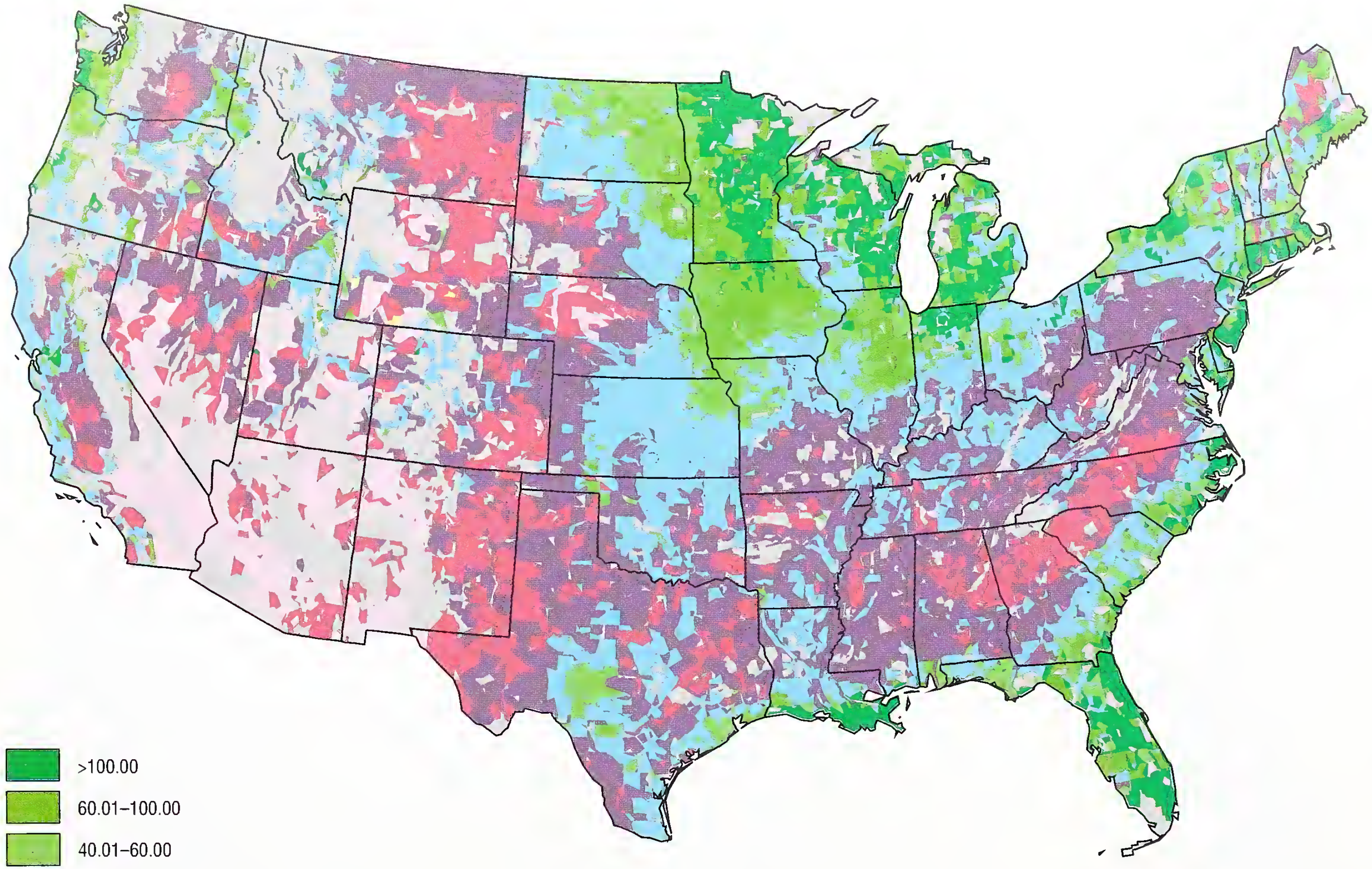
**Figure C–2** Average depth–weighted percent organic carbon in soil surface horizon




**Note**: Average is area-weighted

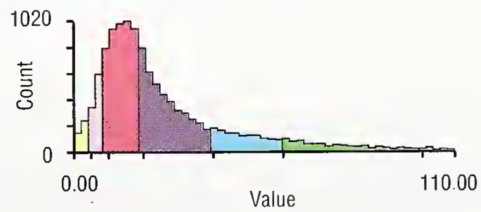



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**Figure C–3** Percent area with soils in Hydrologic Group A

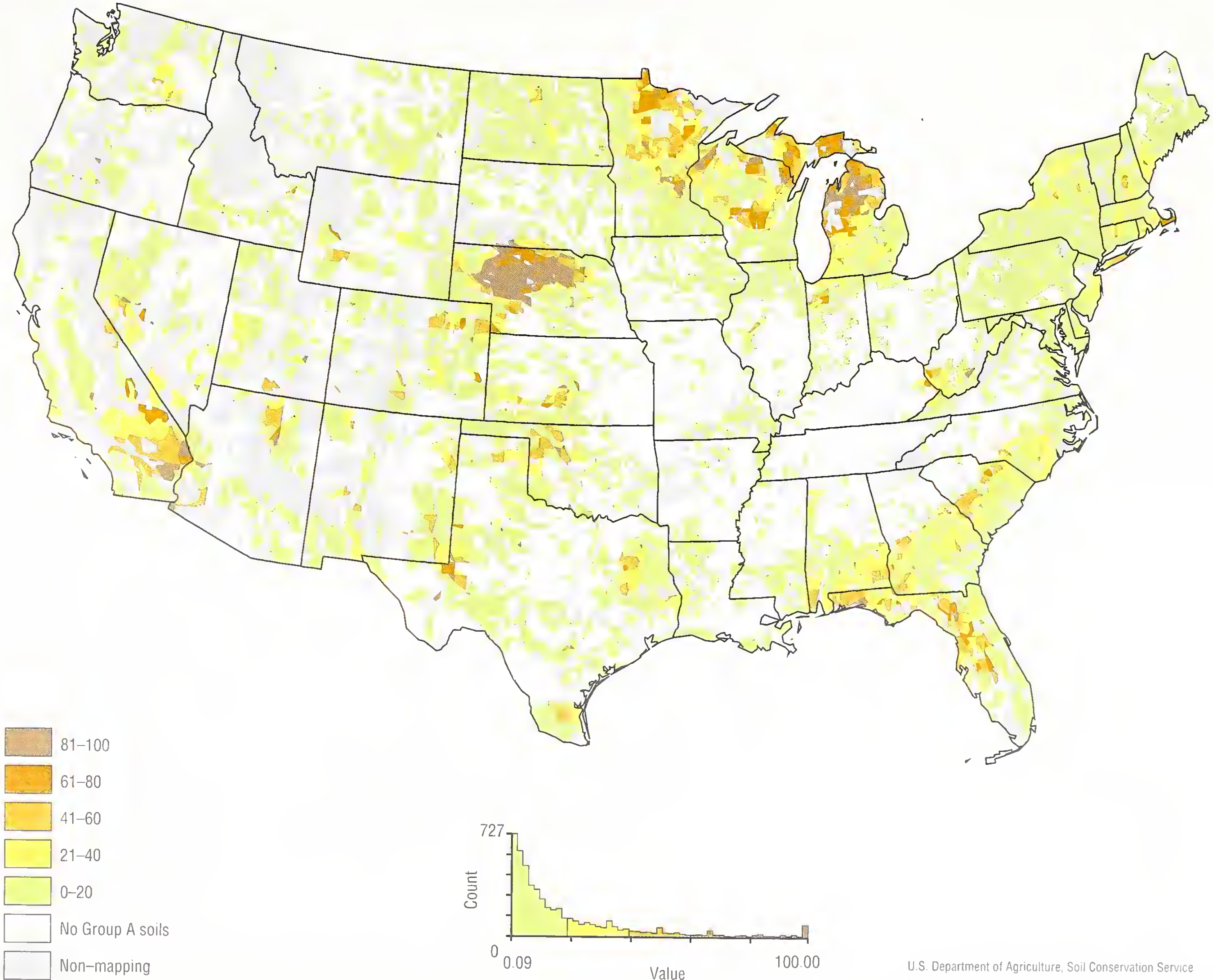


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**Figure C–4** Percent area with soils in Hydrologic Group B

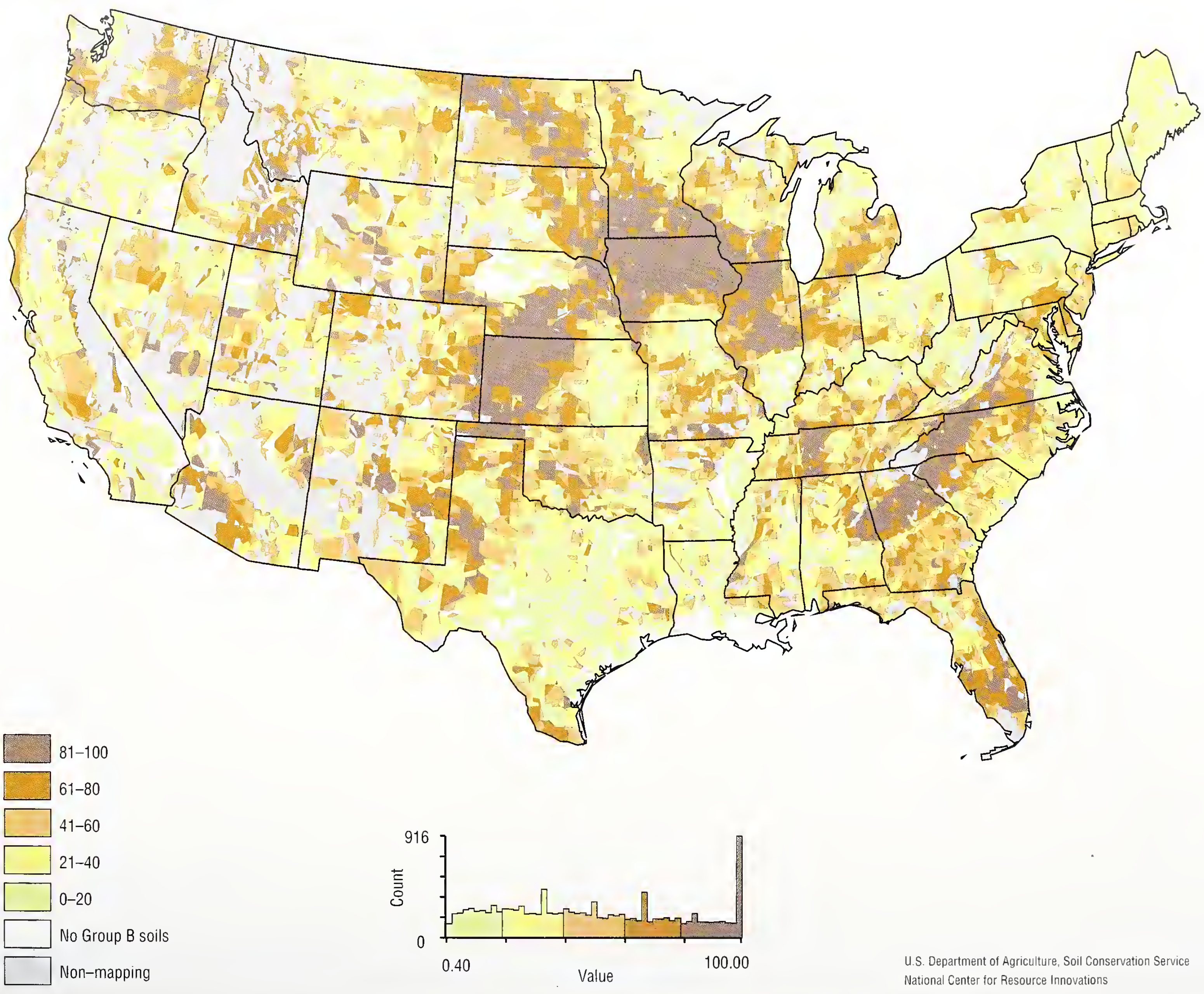


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**Figure C–5** Percent area with soils in Hydrologic Group C

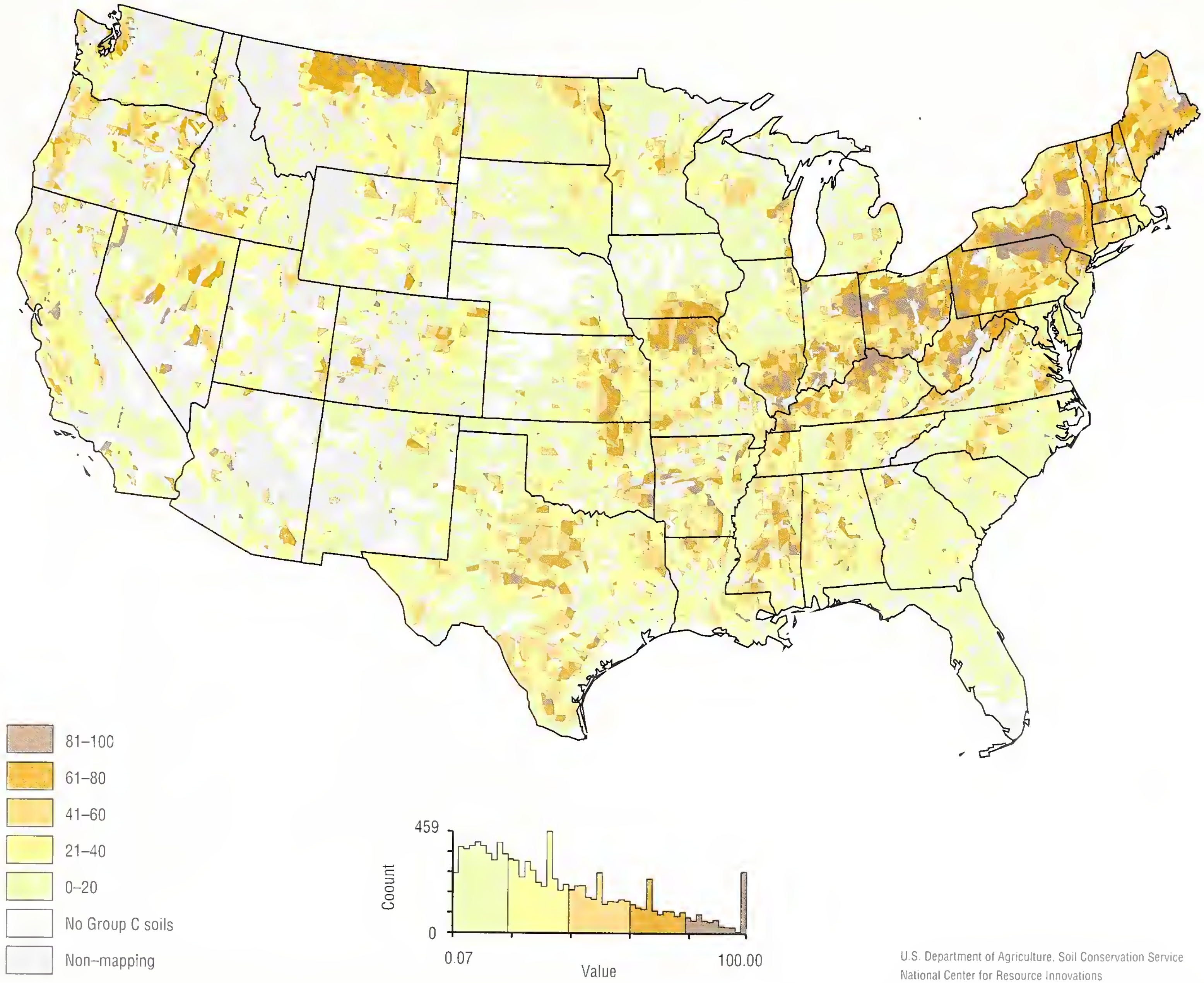

**Figure C–6** Percent area with soils in Hydrologic Group D

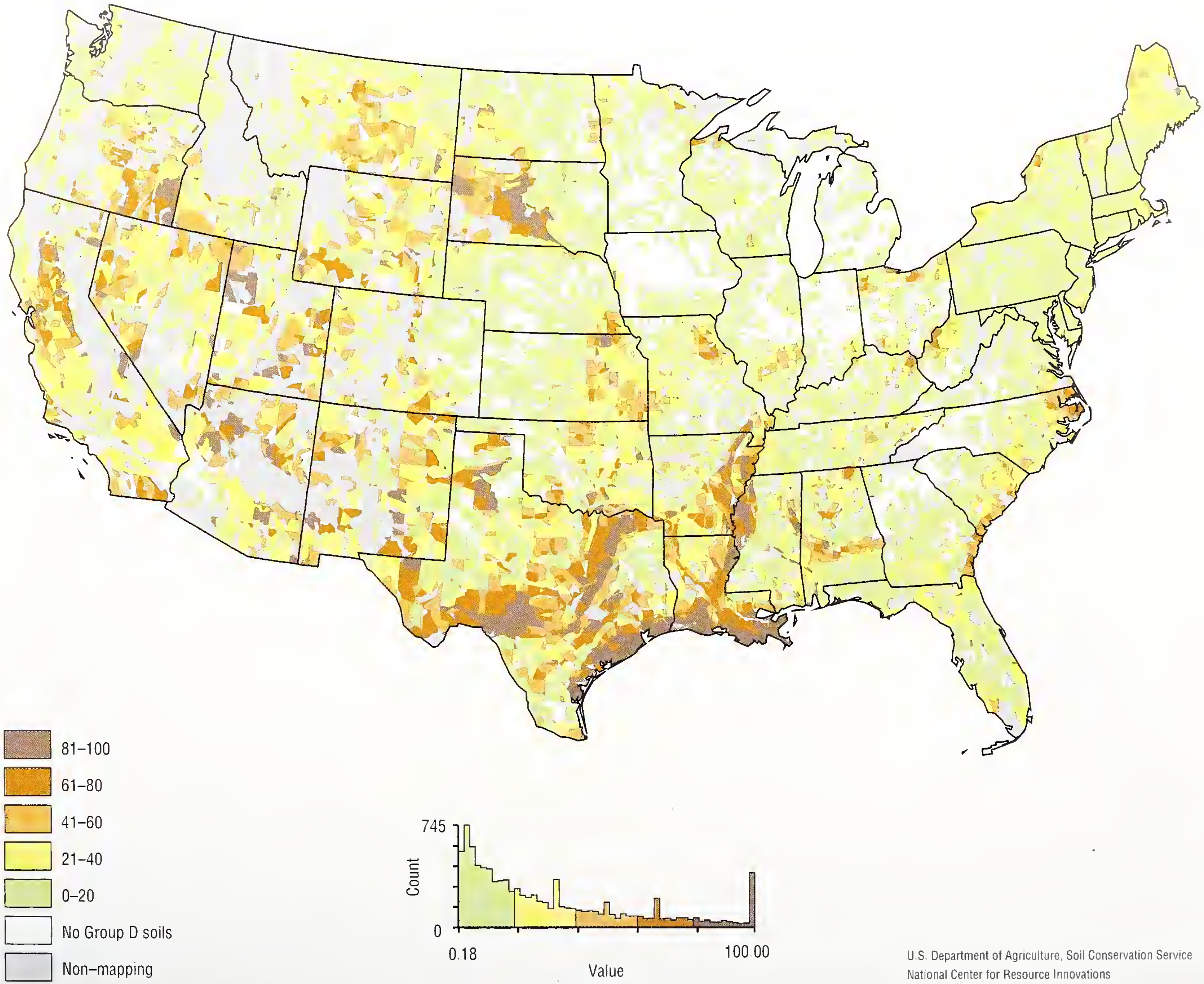

**Figure C–7** Percent cropland area with *Soil-Pesticide Potential 1*

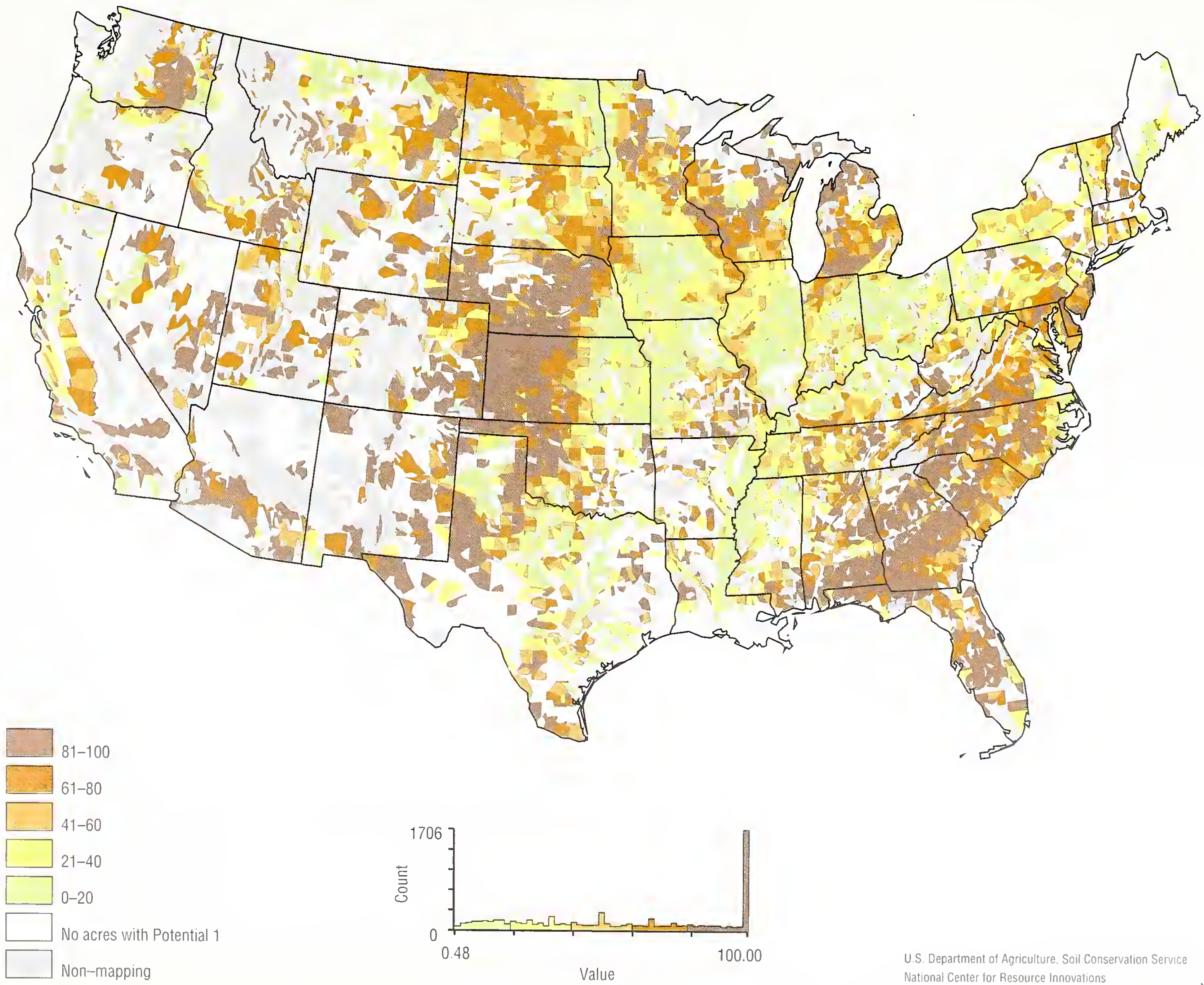


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**Figure C–8** Percent cropland area with *Soil-Pesticide Potential 2*

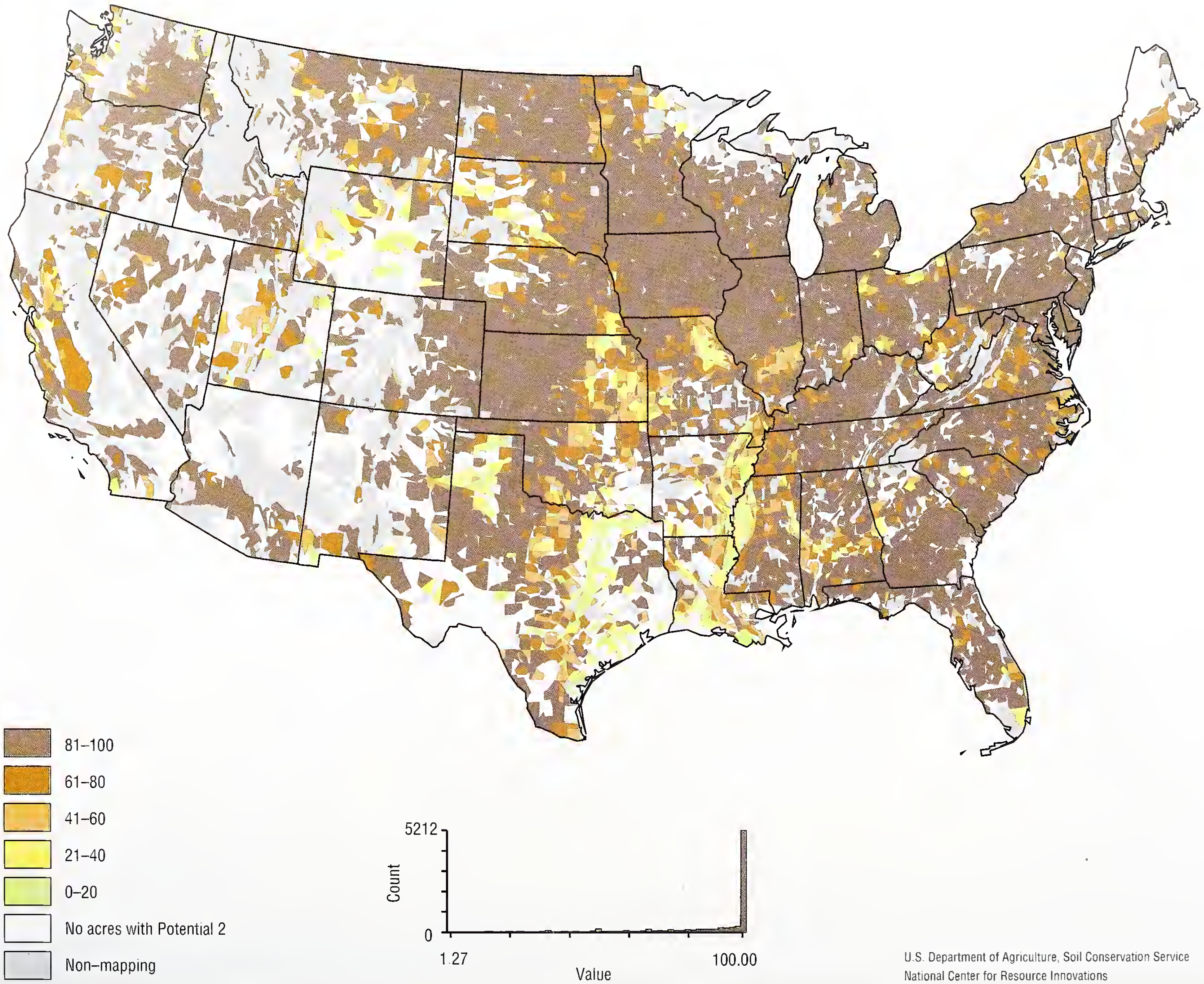


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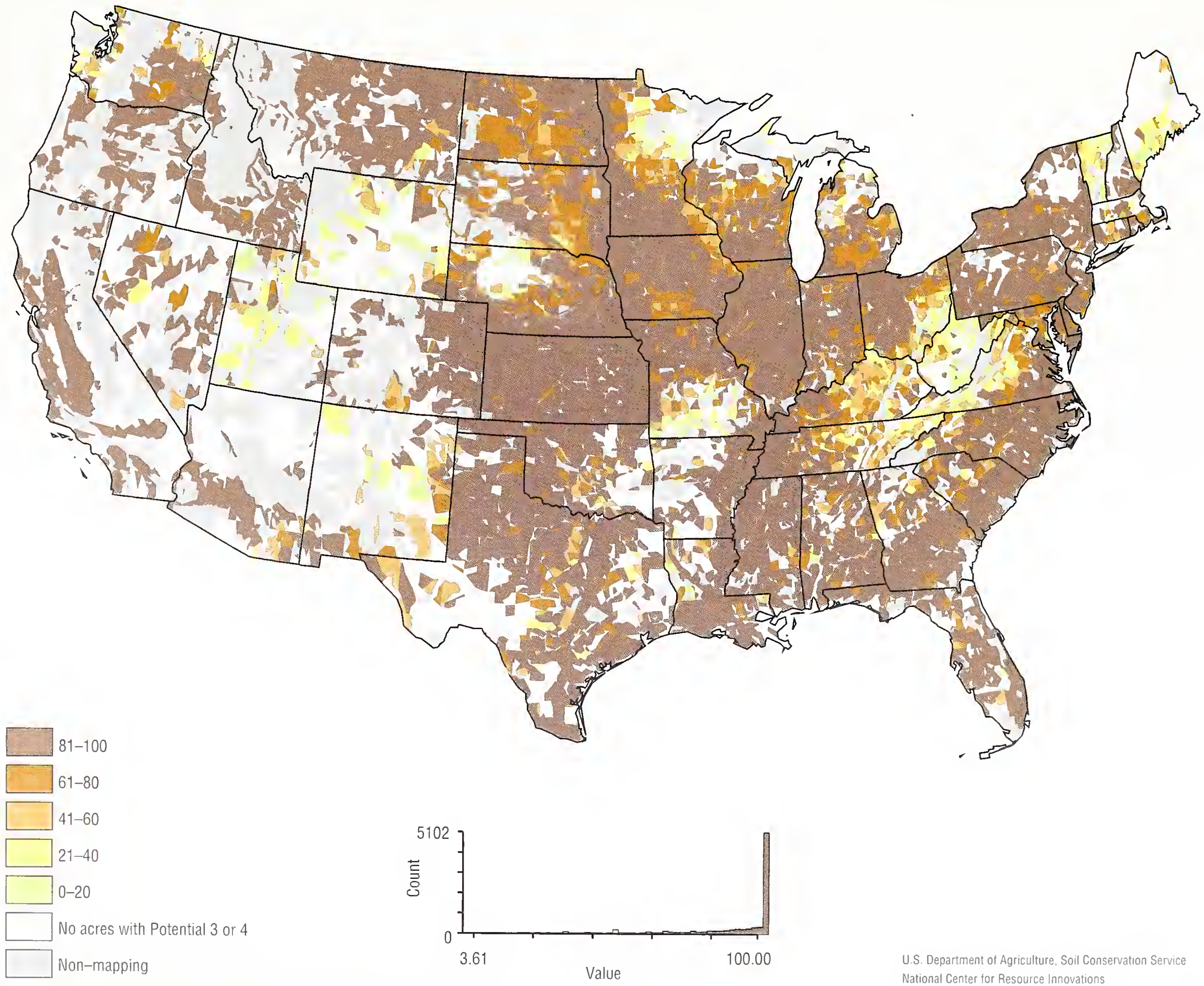
**Figure C–9** Percent cropland area with *Soil-Pesticide Potential 3 or 4*



# Appendix D: A Climatic Modifier for the SCS Soil-Pesticide Interaction Screening Procedure

**J.R. Williams**
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USDA, Soil Conservation Service, retired

The Soil Conservation Service (SCS) developed the Soil-Pesticide Interaction Screening Procedure (SPISP)[1] to evaluate relative loss of pesticides from a field. The SPISP does not contain climate variability. The procedure is a broad based screening procedure with climate introduced after obtaining the results. A nitrogen leaching index developed by Williams and Kissel[2] is applicable to adjusting the SPISP for climatic effect. This paper presents the basics of the Williams and Kissel nitrogen leaching index, its modification to the Percolation Factor (PF), and application to the SPISP.

The quantity of water percolating through the root zone is one of the controlling factors in determining the amount of pesticide that will leach. Appendix C presents factors affecting pesticide movement not related solely to water movement. The distribution and amount of precipitation, crop water use, soil evaporation, and soil characteristics affect the quantity of percolation. The soil characteristics include total water holding capacity, field capacity, wilting point, and hydrologic properties.

## Leaching Index

Williams and Kissel used the EPIC (Erosion-Productivity Impact Calculator) model[3] to estimate nitrate losses to develop a nitrogen leaching index. The nitrogen leaching index estimates average annual percolation below the root zone. This index is used to identify areas of the country that have a high potential for nitrogen leaching.

The nitrogen leaching index was developed using the same conceptual approach as that used to develop the SPISP. The nitrate loss estimated using EPIC is mass, as is the pesticide loss in SPISP. Furthermore, the EPIC model uses methods in CREAMS[4] to estimate effective precipitation, as does the GLEAMS model that was used in the SPISP development.

The procedure to develop the nitrogen leaching index used eight sites representing a variety of soils and climates. The soils varied in texture and hydrologic group. The average annual precipitation ranged from 15 to 48 inches (364 to 1,214 mm), and average annual temperature ranged from 41 to 69 degrees Fahrenheit (5 to 21 °C).

The nitrogen Leaching Index (LI) is a product of two indexes, the Percolation Index (PI) and the Seasonal Index (SI).

$$\mathrm{LI} = \mathrm{SI} \times \mathrm{PI}$$

$$\mathrm{SI} = \left[\frac{(2\mathrm{PW})}{(\mathrm{P})}\right]^{\left(\frac{1}{3}\right)}$$

$$\mathrm{PI} = \frac{(\mathrm{P} - 0.4\mathrm{s})^2}{(\mathrm{P} + 0.6\mathrm{s})}$$

where
PW = the sum of the fall and winter precipitation
P = the annual precipitation
s = dependent on soil hydrologic group (table D–1)

Rainfall occurring when crops are not growing is more likely to percolate deeper than growing season rainfall, some of which is taken up by the plants. The SI accounts for this by putting greater weight on the amount

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1 Goss, Don W., and Don Wauchope. "The SCS/ARS/CES Pesticide Properties Database: II, Using it With Soils Data in a Screening Procedure." *in* Pesticides in the Next Decade: The Challenges Ahead, Diana L. Weigman, ed. Virginia Water Resources Research Center, Blacksburg, VA, 1990, pp. 471-493.

2 Williams, J.R., and D.E. Kissel. Chapter 4, Water Percolation: An Indicator of N Leaching Potential, *in* Managing Nitrogen for Ground Water Quality and Farm Profitability. R.F. Follett, ed. SSSAP, 1991.

3 Williams, J.R., C.A. Jones, and P.T. Dyke. A modeling approach to determining the relationship between erosion and soil productivity. Trans. ASAE 27:129:144, 1984.

4 Knisel, W.G. 1980. Conservation Research Report Number 26. CREAMS a Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. U.S. Department of Agriculture, Science and Education Administration. Conservation Research Report Number 26, 643p.

of fall and winter precipitation than on the growing season precipitation. The fall and winter months are October through March.

PI accounts for the soil characteristics that determine percolation. The s values in the index, shown in table D–1, were estimated by Williams and Kissel by fitting the PI equation to EPIC simulated percolation volumes.

Negative PI values can occur when .4s>P. These P values are all very low, and percolation below the root zone would be unlikely under these conditions. Table D–1 shows for each soil hydrologic group the values of P (annual precipitation) where lower P values will produce negative PI values.

## Percolation Factor

The LI used as a climate modifier for the SPISP permits relating SPISP values across the nation. Converting the LI to the PF required three modifications:

- Adjusting for zero LI values.
- Adjusting for negative PI values.
- Adjusting for irrigation.

A zero LI value multiplied by the SPISP would eliminate any value carried by the SPISP. Zero LI values occur when PI is equal to zero. The value 1 was added to all LI values to eliminate zero PF values.

Similarly, negative values are undesirable in a multiplier for the SPISP. Because negative PIs are associated with very low LI values, negative PIs were set equal to zero in the calculation of the PF.

Irrigation generally increases the volume of water leached below the root zone. The increased volume of water leached below the root zone from irrigation is a function of irrigation efficiency, timing of precipitation events with irrigation, and salt leaching requirements. These factors are so variable with method of irrigation, irrigation water quality, and region of the country that a suitable method of estimating the amount to increase LI because of irrigation could not be established. The consensus among irrigation engineers consulted was to use 5 inches. The NRI point data denoted if more than 50 percent of the water required for plant growth was from irrigation. If this attribute was true, 5 inches was added to the LI. PF was thus calculated as:

$$PF = LI + 1 + \text{adjustment for irrigation}$$

The LI modified to the PF and used as an adjustment to the SPISP is an approximation and represents only a general idea of what may occur at a specific location. This PF modified SPISP is a regional estimation of potential pesticide leaching loss with climate as a consideration.

Some limitations of applying the PF to SPISP are:

- A single crop, corn, was used in the EPIC simulation to develop the SI.
- Single s values for each soil hydrologic group were used to estimate the PI. The s value should be a continuum that reflects surface conditions as well as soil hydrologic group.

**Table D–1** Values for the parameters and the precipitation values for each soil hydrologic group below which PI is negative

| | ---- Soil hydrologic group ---- | | | |
|---|---|---|---|---|
| | A | B | C | D |
| S | 26 | 38 | 49 | 57 |
| P | 11.2 | 8.4 | 6.8 | 6 |

## Calculating PF at NRI sample points

To calculate PF values at each NRI sample point, data on annual precipitation, winter precipitation, and hydrologic soil group are required. Hydrologic soil group data are available for each NRI sample point, as shown previously in figures C–3 through C–6.

Average precipitation data were obtained from EarthInfo's 1988 CD ROM[5] and imputed to NRI sample points on the basis of the proximity of the mapping polygons to 7,744 weather stations.[6] For most stations, a 20-year record was used to calculate the average annual precipitation and the average winter precipitation.[7] LI values were determined at each weather station for each of the four possible hydrologic groups. These four LI values were assigned to each mapping polygon using a Triangular Irregular Network (TIN) and the centroid of each mapping polygon for interpolation. The NRI points in each mapping polygon were then assigned one of the four LI values depending on the soil characteristics at the point.[8]

[5] Trade names mentioned are for specific information and do not constitute a guaranty or warranty of the product by USDA.
[6] See appendix B for a detailed discussion of the cartographic data base, including definition of mapping polygons.
[7] Additional weather stations were available in the data base, but were not used because the historical period covered was not relative to the period covered by the bulk of the data base. Use of weather data that cover markedly different time periods among the weather stations introduces a bias in the percolation factor estimates.
[8] The procedure was successful on all but 937 sample points whose hydrologic group value was missing.

# Appendix E: Use of the RFF Pesticide Data Base to Assess Ground Water Leaching Potential at the National Level

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The Ground Water Vulnerability Index for Pesticides (GWVIP) presented in this publication requires estimates of chemical use at National Resources Inventory (NRI) sample points. Actual observations on chemical use are not available. Instead, chemical use was inferred on the basis of the crop grown and the State in which the NRI sample point was located. Estimates of percent acres treated compiled by Resources For the Future (RFF) were used to estimate the variable PESTWT in the GWVIP equation.

## RFF Chemical Use Data Base

RFF has organized data from publicly available reports and surveys from Federal and State government agencies into a national data base of herbicide, fungicide, and insecticide use in U.S. crop production.[1] These surveys and reports included:

- Surveys conducted by the National Agricultural Statistics Service (NASS) of pesticide use in field crops and vegetable crops.
- Reports for individual states and selected crops funded by USDA's Cooperative Extension Service (CES).
- Pesticide benefit assessments conducted by USDA's National Agricultural Pesticide Impact Assessment Program (NAPIAP).
- Compilations of farmers' pesticide use records into State usage reports (California).

For States and crops not completely covered by the available reports and surveys, RFF conducted a survey of Extension Service plant pathologists, entomologists, and weed specialists for pesticide use profile information. For some States and crops for which there are no published surveys or reports and no expert opinion from crop protection specialists, imputations were made by assuming that the State's pesticide use profile was the same as that of a neighboring State.

The data base was improved by cross-checking estimates of total chemical use with other sources of information. Aggregated national usage profiles were available from EPA.[2] When comparisons revealed significant discrepancies, follow-up contacts were made with Extension Service specialists to confirm or modify the estimates. The State and crop usage profiles for active ingredients were also sent to the chemical registrants for review, and additional discussion with crop protection specialists was arranged to resolve large discrepancies.

The RFF data compilation focused on two parameters:

- The average percent of crop acres in the State treated with the active ingredient.
- The average annual per acre application rate for the active ingredient on the crop in the State.

Chemicals inventoried include 96 herbicides, 57 insecticides, and 32 fungicides. The complete list of chemicals is presented in table E–1. Each pesticide was assigned to one of four pesticide leaching classes—Large, Medium, Small, or Extra Small—according to criteria described in appendix C (table C–4). Fumigants, growth regulators, and desiccants were not systematically covered.

Eighty-four crops are profiled for one or more of the 48 conterminous States. Profiles were prepared for all States having significant acreage of a crop as identified in the 1987 Census of Agriculture. A breakdown by crop of total pounds of active ingredient applied is shown in table E–2. Estimates of total pounds applied were obtained by multiplying the use coefficients by the estimate of crop acreage by State from the 1987 Census of Agriculture. Examples of the coefficients for percent acres treated are shown in table E–3 for corn.

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[1] See Gianessi, Leonard P., and Cynthia Puffer, *Herbicide Use in the United States*, Resources For the Future, December 1990; and Gianessi, Leonard P., and Cynthia Puffer, *Fungicide Use in U.S. Crop Production*, Resources For the Future, April 1992 (preliminary). Preliminary data on insecticides were obtained by personal communication from Leonard Gianessi and Cynthia Puffer.

[2] See USEPA, *Pesticide Industry Sales and Usage: 1988 Market Estimates*, Office of Pesticide Programs, December, 1989.

The RFF data base includes pesticide applications to cropland only. Seed treatments, greenhouse use, ornamental use, and post harvest use are not included. Similarly, the data base excludes use by such noncropland users as homeowners, power companies, highway authorities, forestry operations, and golf courses. In certain geographic areas the noncropland uses of pesticides—especially herbicides—is significant.

Chemical use estimates are not for any specific year, but are intended to represent recent chemical use. Data sources span the years 1987-91.

## Imputing RFF Chemical Use Data to NRI Sample Points

The RFF estimates of percent acres treated were imputed to the 1982 NRI sample points and used to derive the variable PESTWT. RFF data were assigned to NRI sample points by matching the RFF crop type to the NRI crop type for each State. For all but 10 of the NRI crop types, there was a simple one-to-one match (table E–4).

NRI crop types were more specific than the RFF crop types for cool grass hay, warm grass hay, and legume/grass. These three crop types were all matched to the RFF crop type listed as other hay. The pesticide use estimates for other hay were imputed to all three of these NRI crop types.

RFF crop types were more specific than the NRI crop types identified as fruit, nuts, bush fruit, berries, other vegetables, other row crops, and other close-grown crops. For example, the NRI crop type listed as fruit could correspond to one or more of 15 specific types of fruit included in the RFF data base. In these cases, pesticide use was inferred assuming that all possible RFF crops were grown at the NRI sample point.

In addition, it was not possible to match the RFF classification for "pasture" to a corresponding NRI cropland classification. The NRI distinguishes hayland, listed as cropland, from permanent pasture land, which is not listed as cropland. Pasture in the RFF data base includes estimates of Federal and non-Federal rangeland and pastureland acreage.

## Calculating PESTWT

Using the RFF pesticide use data, a PESTWT value was determined for each of the four pesticide leaching classes at each NRI sample point. If the pesticide leaching class contained only a single pesticide, PESTWT was set equal to the percent acres treated for that pesticide. If more than one pesticide was assigned to a pesticide leaching class, PESTWT was set equal to the sum of the percent acres treated within the same pesticide leaching class. If a wide array of chemicals were used on a crop, the NRI sample point could have a PESTWT value for each of the four pesticide leaching classes. It is also possible, and even expected, that PESTWT for one or more pesticide leaching classes could exceed 100 percent. PESTWT values for corn are shown in table E–5.

This procedure was modified for NRI sample points where the RFF crop type was more specific than the NRI crop type. In these situations, PESTWT was determined by summing over the percent acres treated for *all* the RFF crop types corresponding to the more general NRI crop type. Where the same pesticide was used for more than one of the RFF crops in the group, the *average* percent acres treated was used to avoid multiple counting of the same chemical. The average was weighted according to the State acreage of the crops in the group, using acreage data from the 1987 Agriculture Census. Pesticide use for these 7 NRI crop types is, in most cases, overstated.

This approach does not account for differences in chemical use among points where the same crop is grown, but different rotation schemes or management practices are used. For example, PESTWT is the same for corn grown as part of a rotation cropping system as for that in continuous corn operations.

## National Distribution of PESTWT Values

The National distribution of PESTWT values for each of the four pesticide leaching classes is shown in figures E–1, E–2, E–3, and E–4. The maps show the *average* PESTWT for the NRI sample points designated as cropland in each polygon.

**Table E–1** Chemicals identified by active ingredient included in the RFF pesticide data base, the corresponding pesticide leaching class, and estimates of use nationally

| | Pounds active ingredient per year | Pesticide leaching class * |
|---|---|---|
| **Herbicides** | | |
| Acifluorfen | 1,474,837 | Medium |
| Alachlor | 55,187,456 | Medium |
| Ametryn | 186,086 | Medium |
| Asulam | 1,087,521 | Medium |
| Atrazine | 64,235,523 | Large |
| Barban | 51,702 | Small |
| Benefin | 1,167,022 | Small |
| Bensulide | 632,818 | Medium |
| Bentazon | 8,210,758 | Large |
| Bifenox | 125,224 | NA |
| Bromacil | 1,154,951 | Large |
| Bromoxynil | 2,626,834 | Small |
| Butylate | 19,106,876 | Small |
| CDAA | 22,664 | Medium |
| Chloramben | 3,018,741 | Large |
| Chlorimuron | 289,061 | Large |
| Chloroxuron | 62,440 | Small |
| Chlorpropham | 261,845 | Medium |
| Chlorsulfuron | 77,100 | Large |
| Clomazone | 2,714,629 | Medium |
| Clopyralid | 26,247 | Large |
| Cyanazine | 22,894,048 | Medium |
| Cycloate | 1,174,708 | Medium |
| Dalapon | 452,800 | Large |
| DCPA | 2,219,240 | Small |
| Desmedipham | 137,009 | Small |
| Diallate | 120,126 | NA |
| Dicamba | 11,938,489 | Large |
| Dichlobenil | 61,131 | Medium |
| Diclofop | 1,451,669 | Extra small |
| Diethatyl ethyl | 502,440 | Small |
| DifenzoquatT | 282,129 | Extra small |
| Dinoseb | 404,759 | Large |
| Diphenamid | 928,800 | Medium |
| Dipropetryn | 492,624 | Small |
| Diquat | 166,101 | Extra small |
| Diuron | 2,108,897 | Medium |
| DSMA | 1,704,794 | NA |
| Endothall | 198,976 | Medium |
| EPTC | 37,190,842 | Small |
| Ethalfluralin | 3,518,225 | Small |
| Ethofumesate | 327,645 | Medium |
| Fenoxaprop | 26,291 | Small |
| Fluazifop | 731,173 | Small |
| Fluchloralin | 20,148 | Extra small |
| Fluometuron | 2,442,487 | Large |
| Fomesafen | 226,606 | Large |
| Glyphosate | 11,596,723 | Extra small |
| Hexazinone | 343,131 | Large |
| Imazaquin | 1,073,415 | Large |
| Imazathapyr | 332,734 | Large |
| Isopropalin | 97,900 | Small |
| Lactofen | 101,918 | Small |
| Linuron | 2,623,266 | Medium |
| MCPA | 4,338,167 | Large |
| MCPB | 43,788 | Large |
| MCPP | 32,811 | Large |
| Methazole | 299,918 | Small |
| Metolachlor | 49,712,993 | Large |
| Metribuzin | 4,821,961 | Large |
| Metsulfuron | 40,911 | Large |
| Molinate | 4,408,169 | Medium |
| MSMA | 5,064,699 | Extra small |
| Napropamide | 698,617 | Medium |
| Naptalam | 654,715 | Large |
| Norflurazon | 1,767,884 | Medium |
| Oryzalin | 1,426,235 | Small |
| Oxyfluorfen | 599,317 | Extra small |
| Paraquat | 3,025,424 | Extra small |
| Pebulate | 652,898 | Small |
| Pendimethalin | 12,520,949 | Small |
| Phenmedipham | 169,540 | Small |
| Picloram | 3,400,369 | Large |
| Profluralin | 621,196 | Extra small |
| Prometryn | 1,807,206 | Medium |
| Pronamide | 249,400 | Large |
| Propachlor | 3,988,962 | Small |
| Propanil | 7,516,332 | Small |
| Propazine | 4,015,269 | Large |
| Propham | 314,722 | Small |
| Pyrazon | 317,752 | Medium |
| Sethoxydim | 792,493 | Small |
| Siduron | 11,454 | Medium |
| Simazine | 3,963,613 | Large |
| Tebuthiuron | 607,590 | Large |
| Terbacil | 385,175 | Large |
| Terbutryn | 1,113,353 | Small |
| Thiameturon | 54,961 | Medium |
| Thiobencarb | 1,358,632 | Small |
| Triallate | 3,508,659 | Small |
| Triclopyr | 143,409 | Large |
| Tridiphane | 222,697 | Small |
| Trifluralin | 27,119,226 | Small |
| Vernolate | 854,849 | Small |
| 2,4-D | 39,336,184 | Medium |
| 2,4-DB | 1,367,771 | Medium |
| **Fungicides** | | |
| Anilazine | 144,260 | Small |
| Benomyl | 1,967,564 | Small |
| Captan | 4,125,188 | Small |
| Carboxin | 14,844 | Small |
| Chlorothalonil | 11,537,336 | Small |
| Copper | 10,419,318 | NA |
| DCNA | 285,476 | Small |
| Dinocap | 61,076 | Small |
| Dodine | 268,213 | Extra small |
| Etridiazole | 87,164 | Small |
| Fenarimol | 83,235 | NA |
| Ferban | 823,840 | Medium |
| Fosetyl-AL | 160,278 | Extra small |
| Iprodione | 758,483 | Small |
| Mancozeb | 8,207,044 | Small |
| Maneb | 4,289,212 | Small |
| Metalaxyl | 922,251 | Large |
| Metiram | 617,455 | Extra small |
| Myclobutanil | 106,034 | NA |
| Oxytetracycline | 26,928 | NA |
| PCNB | 606,338 | Small |
| Propiconazole | 258,017 | Medium |
| Streptomycin | 127,541 | NA |
| Sulfur | 73,554,411 | NA |
| Thiabendazole | 239,200 | Small |
| Thiophanate methyl | 473,266 | Small |
| Thiram | 185,425 | Small |
| Triadimefon | 207,219 | Small |
| Triforine | 80,596 | Small |
| Triphenyltin hydroxide | 692,655 | Extra small |
| Vinclozolin | 143,001 | NA |
| Ziram | 1,258,443 | NA |
| **Insecticides** | | |
| Abamectin | 5,478 | NA |
| Acephate | 1,441,462 | Small |
| Aldicarb | 4,938,276 | Large |
| Amitraz | 53,405 | Small |
| Azinphos-methyl | 2,308,280 | Small |
| Bifenthrin | 16,615 | Extra small |
| BT | 226,196 | NA |
| Carbaryl | 7,385,432 | Small |
| Carbofuran | 5,796,461 | Large |
| Chlorpyrifos | 16,109,931 | Small |
| Cryolite | 2,789,813 | NA |
| Cyfluthrin | 82,905 | Extra small |
| Cypermethrin | 284,363 | Extra small |
| Cyromazine | 8,567 | Large |
| Diazinon | 2,054,467 | Small |
| Dicofol | 2,049,922 | Extra small |
| Dicrotophos | 431,603 | Large |
| Diflubenzuron | 2,830 | Small |
| Dimethoate | 2,359,787 | Medium |
| Disulfoton | 2,801,056 | Small |
| Endosulfan | 1,772,973 | Extra small |
| Esfenvalerate | 404,457 | Small |
| Ethion | 255,925 | Small |
| Ethoprop | 1,599,748 | Large |
| Ethyl parathion | 3,909,392 | Small |
| Fenamiphos | 436,309 | Large |
| Fenbutatin oxide | 738,261 | Small |
| Fenvalerate | 215,784 | Small |
| Fonofos | 3,906,195 | Small |
| Formetanate HCL | 410,946 | NA |
| Lambdacyhalothrin | 53,293 | Extra small |
| Lindane | 47,309 | Medium |
| Malathion | 5,153,324 | Small |
| Metaldehyde | 43,650 | Small |
| Methamidophos | 1,015,522 | Medium |
| Methindathion | 423,298 | Small |
| Methomyl | 2,866,511 | NA |
| Methoxychlor | 92,729 | Extra small |
| Methyl parathion | 3,505,805 | Small |
| Mevinphos | 453,844 | Small |
| Naled | 218,938 | Small |
| Oil | 57,128,946 | Small |
| Oxamyl | 486,348 | Small |
| Oxydemeton-methyl | 652,066 | Large |
| Oxythioquinox | 56,248 | Small |
| Permethrin | 993,978 | Extra small |
| Phorate | 4,735,952 | Small |
| Phosmet | 796,636 | Small |
| Profenofos | 434,308 | Small |
| Propargite | 3,893,036 | Small |
| Sulprofos | 199,339 | Extra small |
| Tefluthrin | 195,924 | NA |
| Terbufos | 7,129,717 | Small |
| Thiodicarb | 967,237 | Small |
| Tralomethrin | 115,867 | Extra small |
| Trichlorfon | 51,748 | Large |
| Trimethacarb | 125,069 | Medium |

* NA=ranking not available

**Table E–2** Estimated annual pesticide usage in pounds per year of active ingredient by crop for the RFF pesticides for which pesticide leaching classes were available

| Crop | Herbicides | Insecticides | Fungicides | All |
|---|---|---|---|---|
| Alfalfa | 7,447,331 | 3,199,587 | 0 | 10,646,918 |
| Almonds | 657,223 | 9,273,591 | 1,527,573 | 11,458,387 |
| Apples | 594,889 | 6,010,558 | 4,819,025 | 11,424,472 |
| Apricots | 10,618 | 341,796 | 31,613 | 384,027 |
| Artichokes | 23,428 | 54,919 | 949 | 79,296 |
| Asparagus | 307,288 | 208,789 | 54,514 | 570,591 |
| Avocados | 67,661 | 8,596 | 4,373 | 80,630 |
| Barley | 4,765,974 | 149,780 | 10,523 | 4,926,277 |
| Beets | 66,951 | 9,791 | 0 | 76,742 |
| Blackberries | 18,976 | 42,168 | 10,156 | 71,300 |
| Blueberries | 89,508 | 83,906 | 320,127 | 493,541 |
| Broccoli | 425,734 | 357,236 | 46,638 | 829,608 |
| Brussel spouts | 524 | 34,426 | 9,322 | 44,272 |
| Cabbage | 229,713 | 288,736 | 221,504 | 739,953 |
| Cantaloupes | 188,618 | 107,609 | 197,007 | 493,234 |
| Carrots | 159,820 | 68,513 | 156,163 | 384,496 |
| Cauliflower | 312,051 | 193,453 | 39,420 | 544,924 |
| Celery | 80,637 | 143,629 | 254,801 | 479,067 |
| Cherries | 70,733 | 1,093,197 | 468,745 | 1,632,675 |
| Citrus | 3,239,952 | 41,588,810 | 8,736 | 44,837,498 |
| Collards | 33,492 | 18,430 | 0 | 51,922 |
| Corn | 205,542,290 | 29,101,123 | 0 | 234,643,413 |
| Cotton | 24,781,957 | 12,970,881 | 465,253 | 38,218,091 |
| Cranberries | 83,923 | 135,716 | 224,420 | 444,059 |
| Cucumbers | 247,628 | 113,546 | 534,355 | 895,529 |
| Dates | 4,702 | 27,473 | 0 | 32,175 |
| Dry beans | 4,713,110 | 581,201 | 2,041,360 | 7,335,671 |
| Dry peas | 198,003 | 42,948 | 937 | 241,888 |
| Eggplant | 3,225 | 6,238 | 9,791 | 19,254 |
| Figs | 11,631 | 751 | 0 | 12,382 |
| Filberts | 30,230 | 158,686 | 0 | 188,916 |
| Flax | 174,179 | 7,412 | 0 | 181,591 |
| Garlic | 149,875 | 792 | 7,747 | 158,414 |
| Grapes | 1,943,741 | 1,666,989 | 973,112 | 4,583,842 |
| Green beans | 790,374 | 513,158 | 200,268 | 1,503,800 |
| Green onions | 86,530 | 2,306 | 1,104 | 89,940 |
| Green peas | 384,223 | 39,560 | 21,795 | 445,578 |
| Guar | 2,382 | 0 | 0 | 2,382 |
| Hops | 6,901 | 205,645 | 4,621 | 217,167 |
| Hot peppers | 48,452 | 2,599 | 88 | 51,139 |
| Kiwi | 10,480 | 13,018 | 0 | 23,498 |
| Lettuce | 298,671 | 816,857 | 679,412 | 1,794,940 |
| Melons | 23,353 | 252,633 | 21,749 | 297,735 |
| Mint | 131,355 | 239,990 | 641 | 371,986 |
| Nectarines | 29,768 | 960,412 | 61,978 | 1,052,158 |
| Oats | 898,775 | 114,495 | 8,652 | 1,021,922 |
| Okra | 1,470 | 2,980 | 0 | 4,450 |
| Olives | 31,400 | 449,648 | 0 | 481,048 |
| Onions | 778,785 | 241,998 | 596,589 | 1,617,372 |
| Other hay | 11,406,033 | 1,020,546 | 0 | 12,426,579 |
| Parsley | 3,100 | 1,005 | 0 | 4,105 |
| Pasture | 27,505,789 | 1,249,719 | 0 | 28,755,508 |
| Peaches | 260,308 | 3,575,788 | 1,244,420 | 5,080,516 |
| Peanuts | 5,007,091 | 2,805,797 | 6,120,552 | 13,933,440 |
| Pears | 70,377 | 3,788,029 | 77,838 | 3,936,244 |
| Pecans | 250,055 | 1,381,494 | 902,265 | 2,533,814 |
| Pistachios | 59,973 | 49,011 | 638 | 109,622 |
| Plums | 146,101 | 2,573,076 | 139,145 | 2,858,322 |
| Pomegrantes | 3,622 | 0 | 0 | 3,622 |
| Potatoes | 2,617,251 | 3,253,838 | 4,293,163 | 10,164,252 |
| Pumpkins | 43,323 | 27,616 | 191,046 | 261,985 |
| Radiishes | 20,260 | 33,734 | 0 | 53,994 |
| Raspberries | 37,399 | 64,479 | 43,211 | 145,089 |
| Rice | 14,387,796 | 628,721 | 354,995 | 15,371,512 |
| Rye | 36,446 | 3,191 | 307 | 39,944 |
| Safflower | 130,698 | 84,239 | 0 | 214,937 |
| Seed crops | 1,970,721 | 124,824 | 128,087 | 2,223,632 |
| Sod | 532,020 | 1,227 | 0 | 533,247 |
| Sorghum | 22,329,052 | 4,727,634 | 0 | 27,056,686 |
| Soybeans | 82,491,237 | 2,190,014 | 883,976 | 85,565,227 |
| Spinach | 110,183 | 29,272 | 24,745 | 164,200 |
| Squash | 104,584 | 52,106 | 451,527 | 608,217 |
| Strawberries | 175,071 | 224,724 | 470,258 | 870,053 |
| Sugarbeets | 3,129,627 | 1,111,405 | 75,349 | 4,316,381 |
| Sugarcane | 3,106,693 | 670,354 | 0 | 3,777,047 |
| Sunflowers | 1,506,372 | 625,454 | 0 | 2,131,826 |
| Sweet corn | 1,891,966 | 1,008,537 | 631,144 | 3,531,647 |
| Sweet peppers | 168,271 | 155,165 | 283,165 | 606,601 |
| Sweet potatoes | 234,910 | 265,294 | 70 | 500,274 |
| Tabacco | 1,398,730 | 1,338,629 | 597,251 | 3,334,610 |
| Tomatoes | 1,167,094 | 987,616 | 3,455,286 | 5,609,996 |
| Walnuts | 301,660 | 511,245 | 0 | 812,905 |
| Watermelons | 314,330 | 160,781 | 1,075,285 | 1,550,396 |
| Wheat | 17,895,028 | 3,467,474 | 1,533,616 | 22,896,118 |
| **All Crops** | 461,011,705 | 150,138,613 | 37,012,400 | 648,162,718 |

**Table E–3** Percent acres treated coefficients from the RFF pesticide data base for corn for selected states

| | Texas | Florida | Iowa | Nebraska | Indiana | California | North Carolina | Delaware |
|---|---|---|---|---|---|---|---|---|
| Alachlor | 35 | 40 | 22 | 39 | 43 | 30 | 43 | 50 |
| Ametryn | 0 | 11 | 0 | 0 | 0 | 0 | 2 | 0 |
| Atrazine | 80 | 65 | 58 | 78 | 87 | 10 | 78 | 95 |
| Bentazon | 2 | 0 | 3 | 3 | 0 | 0 | 0 | 0 |
| Bifenthrin | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bromoxynil | 6 | 0 | 18 | 2 | 0 | 0 | 0 | 0 |
| BT | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| Butylate | 3 | 25 | 4 | 8 | 10 | 5 | 12 | 5 |
| Carbaryl | 11 | 12 | 0 | 0 | 0 | 1 | 1 | 3 |
| Carbofuran | 12 | 15 | 1 | 9 | 5 | 0 | 5 | 40 |
| Chlorpyrifos | 8 | 46 | 12 | 15 | 8 | 1 | 57 | 16 |
| Cyanazine | 8 | 0 | 18 | 20 | 18 | 0 | 2 | 20 |
| Diazinon | 2 | 1 | 0 | 5 | 0 | 0 | 0 | 0 |
| Dicamba | 6 | 10 | 21 | 9 | 14 | 5 | 7 | 25 |
| Dimethoate | 7 | 4 | 0 | 2 | 0 | 0 | 0 | 0 |
| Disulfoton | 48 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| EPTC | 5 | 0 | 14 | 4 | 1 | 0 | 8 | 5 |
| Esfenvalerate | 7 | 12 | 0 | 1 | 0 | 1 | 1 | 1 |
| Ethoprop | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| Ethyl parathion | 1 | 12 | 0 | 6 | 0 | 0 | 0 | 0 |
| Fenvalerate | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 20 |
| Fonofos | 8 | 5 | 6 | 6 | 5 | 1 | 1 | 2 |
| Glyphosate | 5 | 0 | 1 | 1 | 1 | 0 | 5 | 5 |
| Malathion | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 1 |
| Methomyl | 3 | 12 | 0 | 0 | 0 | 2 | 4 | 3 |
| Methyl parathion | 1 | 19 | 0 | 14 | 0 | 0 | 0 | 25 |
| Metolachlor | 35 | 15 | 35 | 19 | 23 | 30 | 18 | 50 |
| Mevinphos | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| Paraquat | 1 | 0 | 0 | 0 | 2 | 0 | 16 | 10 |
| Pendimethalin | 13 | 15 | 3 | 0 | 2 | 10 | 0 | 0 |
| Permethrin | 1 | 8 | 1 | 3 | 2 | 3 | 1 | 3 |
| Phorate | 1 | 5 | 2 | 2 | 2 | 2 | 2 | 1 |
| Propachlor | 0 | 0 | 3 | 1 | 0 | 0 | 0 | 0 |
| Propargite | 7 | 0 | 0 | 1 | 0 | 7 | 0 | 0 |
| Simazine | 3 | 0 | 0 | 0 | 1 | 0 | 8 | 20 |
| Tefluthrin | 8 | 0 | 1 | 5 | 4 | 0 | 0 | 0 |
| Terbufos | 18 | 25 | 13 | 14 | 8 | 0 | 12 | 18 |
| Trichlorfon | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tridiphane | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| Trifluralin | 4 | 15 | 0 | 0 | 0 | 0 | 0 | 0 |
| Trimethacarb | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Vernolate | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 |
| 2,4-D | 6 | 35 | 15 | 12 | 10 | 6 | 29 | 50 |

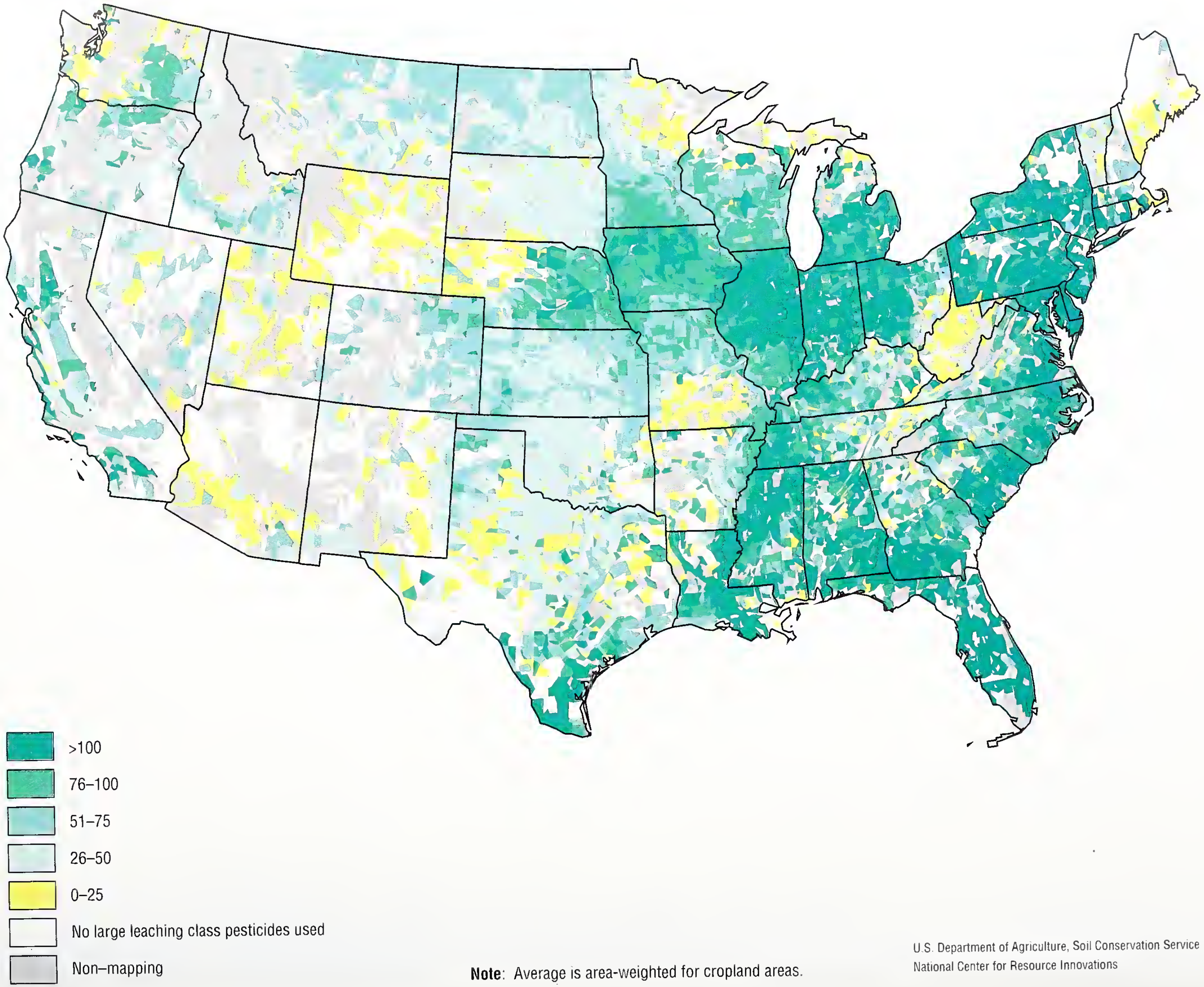
**Table E–4** Correspondence between NRI crop names and RFF crop names

| NRI crop name | RFF crop name | Number of RFF pesticides | NRI crop name | RFF crop name | Number of RFF pesticides |
|---|---|---|---|---|---|
| Fruit | Apples | 60 | Other vegetables | Celery | 28 |
| Fruit | Apricots | 25 | Other vegetables | Collards | 17 |
| Fruit | Avocados | 14 | Other vegetables | Cucumbers | 42 |
| Fruit | Cherries | 43 | Other vegetables | Dry beans | 40 |
| Fruit | Citrus | 41 | Other vegetables | Dry peas | 22 |
| Fruit | Dates | 3 | Other vegetables | Eggplant | 22 |
| Fruit | Figs | 8 | | | |
| Fruit | Kiwi | 12 | Other vegetables | Garlic | 13 |
| Fruit | Melons | 30 | Other vegetables | Green beans | 49 |
| Fruit | Nectarines | 32 | Other vegetables | Green onions | 11 |
| Fruit | Peaches | 51 | Other vegetables | Green peas | 38 |
| Fruit | Pears | 47 | | | |
| Fruit | Plums | 34 | Other vegetables | Hot peppers | 16 |
| Fruit | Pomegranates | 3 | Other vegetables | Lettuce | 32 |
| Fruit | Watermelons | 43 | Other vegetables | Okra | 5 |
| | | | Other vegetables | Onions | 44 |
| Nuts | Almonds | 30 | Other vegetables | Parsley | 6 |
| Nuts | Filberts | 16 | | | |
| Nuts | Pecans | 32 | Other vegetables | Pumpkins | 29 |
| Nuts | Pistachios | 11 | Other vegetables | Radishes | 10 |
| Nuts | Walnuts | 26 | Other vegetables | Spinach | 27 |
| | | | Other vegetables | Squash | 36 |
| Vineyard | Grapes | 54 | Other vegetables | Sweet corn | 44 |
| Bush Fruit | Blueberries | 30 | Other vegetables | Sweet peppers | 42 |
| Bush Fruit | Olives | 13 | Other vegetables | Tomatoes | 47 |
| | | | | | |
| Berries | Blackberries | 18 | Other row crops | Guar | 1 |
| Berries | Cranberries | 24 | Other row crops | Hops | 15 |
| Berries | Raspberries | 33 | Other row crops | Mint | 20 |
| Berries | Strawberries | 47 | Other row crops | Seed crops | 50 |
| | | | Other row crops | Sugarcane | 17 |
| Corn | Corn | 44 | Other row crops | Sweet potatoes | 16 |
| Sorghum | Sorghum | 32 | | | |
| Soybeans | Soybeans | 49 | Sunflowers | Sunflowers | 18 |
| Cotton | Cotton | 65 | Wheat | Wheat | 38 |
| Peanuts | Peanuts | 46 | Oats | Oats | 19 |
| Tobacco | Tobacco | 25 | Rice | Rice | 22 |
| Sugar beets | Sugarbeets | 42 | Barley | Barley | 30 |
| Potatoes | Potatoes | 54 | Flax | Flax | 15 |
| | | | | | |
| Other vegetables | Artichokes | 19 | Other close grown crops | Rye | 11 |
| Other vegetables | Asparagus | 29 | Other close grown crops | Safflower | 8 |
| Other vegetables | Beets | 18 | | | |
| Other vegetables | Broccoli | 35 | Cool grass hay | Other hay | 11 |
| Other vegetables | Brussel sprouts | 17 | Warm grass hay | Other hay | 11 |
| | | | Legume/hay | Alfalfa | 45 |
| Other vegetables | Cabbage | 36 | Legume/grass | Other hay | 11 |
| Other vegetables | Cantaloupes | 40 | | | |
| Other vegetables | Carrots | 26 | Other farmland | Sod | 20 |
| Other vegetables | Cauliflower | 38 | (none) | Pasture | 10 |

Table E–5 PESTWT values for corn for each of the four pesticide leaching classes

| | Large | Medium | Small | Very small |
|---|---|---|---|---|
| Alabama | 140 | 40 | 37 | 9 |
| Arizona | 115 | 40 | 15 | 0 |
| Arkansas | 190 | 78 | 45 | 1 |
| California | 45 | 36 | 33 | 3 |
| Colorado | 112 | 81 | 137 | 3 |
| Connecticut | 132 | 27 | 30 | 3 |
| Delaware | 230 | 120 | 97 | 18 |
| Florida | 118 | 90 | 212 | 8 |
| Georgia | 133 | 38 | 130 | 8 |
| Idaho | 55 | 35 | 95 | 6 |
| Illinois | 135 | 53 | 53 | 5 |
| Indiana | 130 | 72 | 36 | 5 |
| Iowa | 118 | 55 | 77 | 2 |
| Kansas | 117 | 41 | 93 | 21 |
| Kentucky | 132 | 26 | 53 | 31 |
| Louisiana | 162 | 50 | 102 | 1 |
| Maine | 110 | 40 | 10 | 0 |
| Maryland | 195 | 75 | 74 | 64 |
| Massachusetts | 120 | 40 | 50 | 0 |
| Michigan | 125 | 56 | 57 | 6 |
| Minnesota | 85 | 64 | 59 | 7 |
| Mississippi | 155 | 40 | 68 | 13 |
| Missouri | 106 | 52 | 53 | 7 |
| Montana | 19 | 43 | 12 | 0 |
| Nebraska | 120 | 73 | 80 | 4 |
| Nevada | 0 | 32 | 10 | 0 |
| New Hampshire | 64 | 14 | 10 | 7 |
| New Jersey | 152 | 79 | 29 | 19 |
| New Mexico | 65 | 52 | 38 | 5 |
| New York | 133 | 36 | 81 | 20 |
| North Carolina | 116 | 76 | 95 | 22 |
| North Dakota | 33 | 38 | 53 | 1 |
| Ohio | 147 | 70 | 38 | 12 |
| Oklahoma | 197 | 40 | 48 | 15 |
| Oregon | 83 | 57 | 76 | 32 |
| Pennsylvania | 154 | 43 | 60 | 27 |
| Rhode Island | 140 | 75 | 20 | 0 |
| South Carolina | 139 | 115 | 89 | 19 |
| South Dakota | 62 | 55 | 65 | 1 |
| Tennessee | 120 | 36 | 88 | 15 |
| Texas | 138 | 56 | 144 | 10 |
| Utah | 61 | 30 | 39 | 0 |
| Vermont | 151 | 62 | 13 | 4 |
| Virginia | 172 | 39 | 52 | 73 |
| Washington | 45 | 35 | 40 | 6 |
| West Virginia | 154 | 61 | 27 | 75 |
| Wisconsin | 92 | 49 | 49 | 6 |
| Wyoming | 60 | 77 | 82 | 0 |

**Figure E–1** Average PESTWT value for pesticides with a *Large Pesticide Leaching Class*




**Note**: Average is area-weighted for cropland areas.

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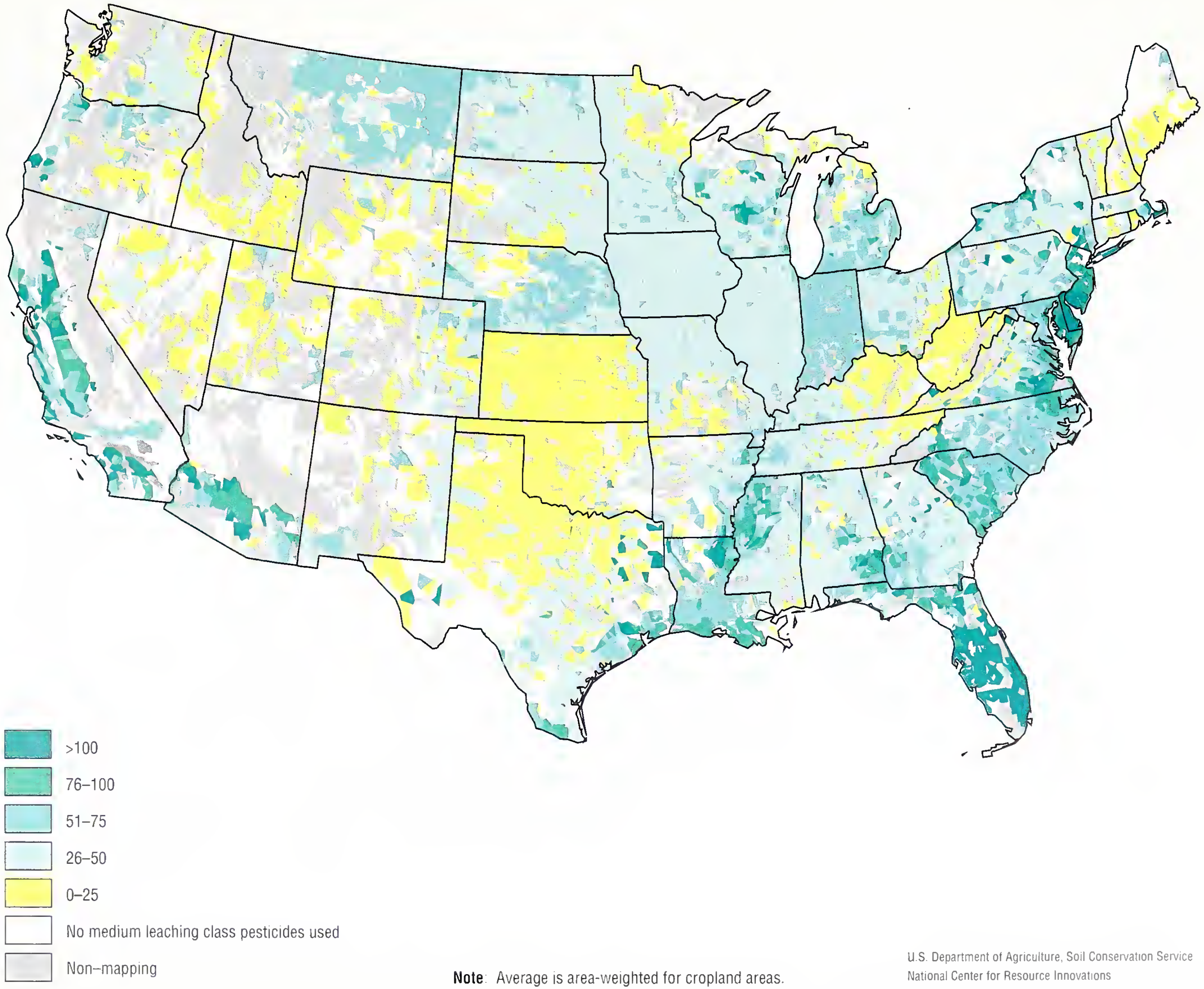
**Figure E–2** Average PESTWT value for pesticides with a *Medium Pesticide Leaching Class*




**Note**: Average is area-weighted for cropland areas.

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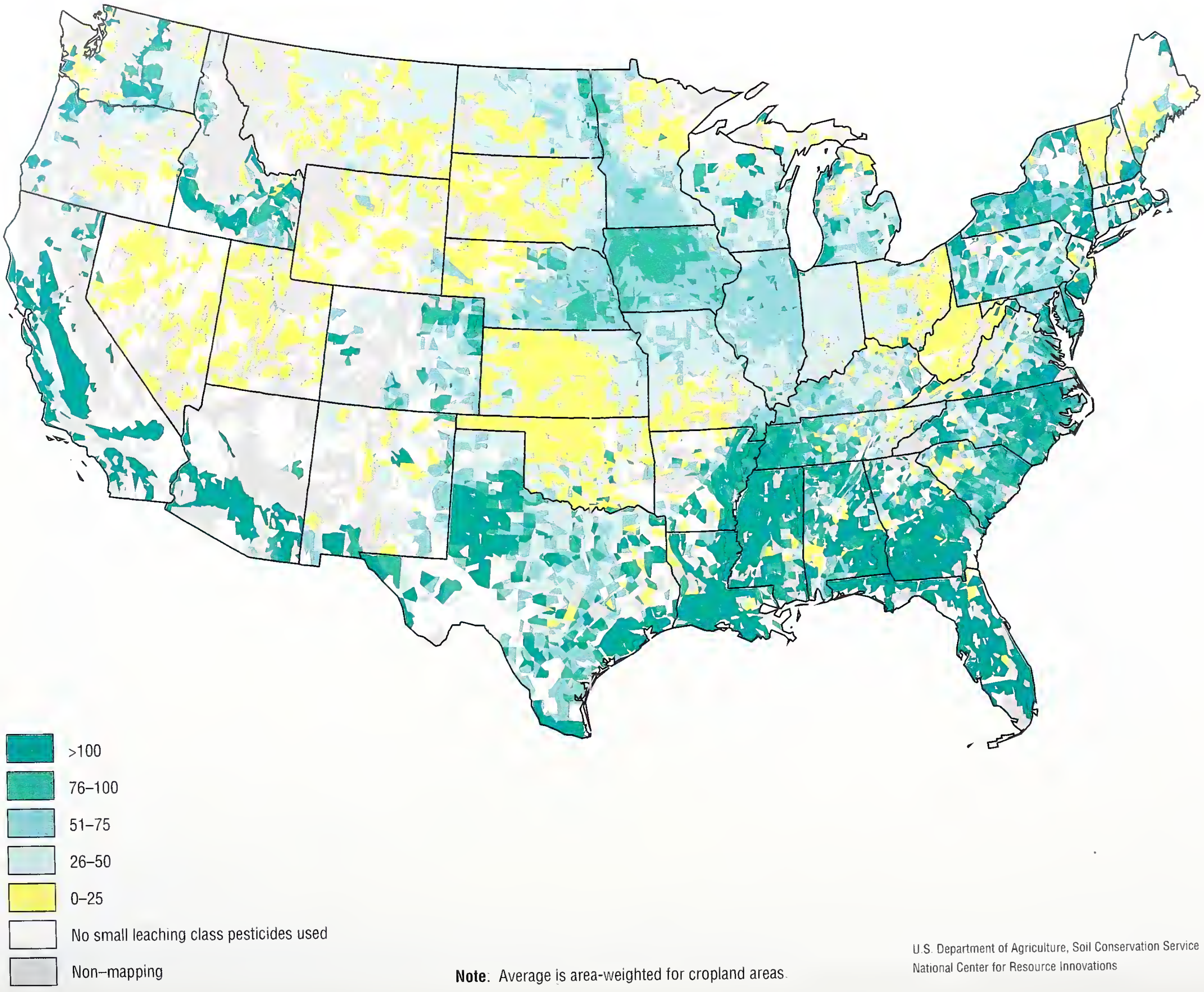
**Figure E–3** Average PESTWT value for pesticides with a *Small Pesticide Leaching Class*




**Note**: Average is area-weighted for cropland areas.

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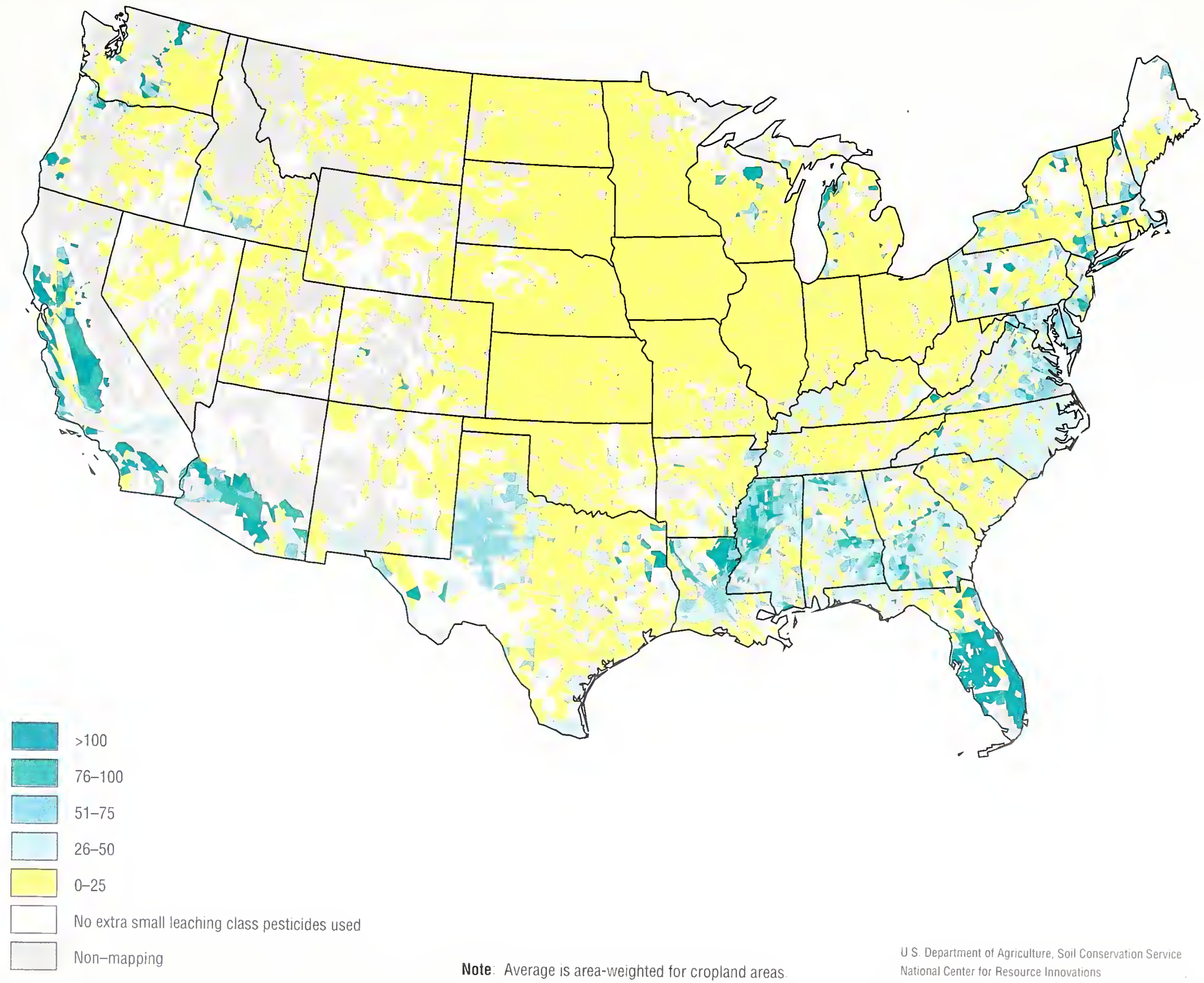
**Figure E–4** Average PESTWT value for pesticides with a *Extra Small Pesticide Leaching Class*




**Note**: Average is area-weighted for cropland areas.

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# Appendix F: An Estimate of Excess Nitrogen Fertilizer for the U.S.

**Wen-Yuan Huang**
Economic Research Service

This paper describes a nitrogen budget method for estimating excess nitrogen fertilizer available for leaching in U.S. crop production.[1] County level estimates of excess nitrogen fertilizer applied were estimated for three crops: cotton, corn, and wheat. More than 65 percent of the nitrogen fertilizer applied in the United States is used on these crops.[2] These estimates were imputed to 1982 NRI sample points and used to estimate the Ground Water Vulnerability Index for Nitrogen Fertilizer (GWVIN) presented in this publication.

### The Approach

The amount of nitrogen fertilizer available for leaching is difficult to estimate even for a small area, such as a field. Factors that determine the fate of nitrogen in soil are often highly variable. Moreover, distinguishing between leaching and denitrification and between nitrogen losses and changes in the organic nitrogen level in the soil is difficult.[3] Use of a crop-soil-hydrologic model to estimate nitrogen fertilizer available for leaching is data intensive and time consuming even at a single point. Such models are impractical for use in making county, State, and National estimates.

An approximation of the amount of nitrogen available for leaching can be made by estimating the amount of excess nitrogen fertilizer applied using a nitrogen budget approach. The nitrogen budget approach is based on the concept that the nitrogen inputs into a particular system minus the nitrogen outputs must equal the change of nitrogen stored within the system. Meisinger and Randall used a nitrogen budget approach to estimate long-term potential leachable nitrogen.[4] Pierce, Shaffer, and Halvorson developed a simpler computation for nitrogen annually available for leaching that is less data intensive, but the data requirements still exceed availability for purposes of making national estimates.[5]

A simpler algorithm is presented here that focuses only on excess nitrogen produced by human farming activities and that can be estimated using available national-level data on soils, farming practices, and fertilizer use.

Excess nitrogen as measured here is defined as the difference between the amount of nitrogen fertilizer applied and the amount of nitrogen taken up by the crop and removed from the field. The calculation is made as follows:

$$N_e = N_f - (N_g + N_s - N_l)$$

where:

$N_e$ = excess nitrogen fertilizer applied.
$N_f$ = amount of commercial nitrogen fertilizer applied.
$N_g$ = nitrogen content of harvested part of crop (i.e., grain).
$N_s$ = nitrogen content of other plant material removed from the field.
$N_l$ = nitrogen credit from previous legume crops.

All components of the algorithm are estimated in units of pounds of nitrogen per acre. County level estimates of excess nitrogen fertilizer applied per acre and per crop were produced in this manner and used as the variable EXCESSN in the GWVIN algorithm.

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[1] See also Wen-yuan Huang, David Westernbarger, and Karen Mizer. "The Magnitude and Distribution of U.S. Cropland Vulnerable to Nitrate Leaching," Making Information Work. Conference Proceedings, National Governors Association. January 18-23, 1992. Washington DC.
[2] Vroomen, H. *Fertilizer Use and Price Statistics, 1960-88,* (updated), Statistical Bulletin Number 780. U.S. Department of Agriculture, Economic Research Service, Washington DC. 1990.
[3] Blackmer, A.M. "Losses and Transport of Nitrogen from Soil." Chapter 5 in *Rural Groundwater Contamination.* F. D'itri and L. Wolfson, Lewis Publishers, Inc., Chelsea, MI, 1987.
[4] Meisinger, J.J., and G.W. Randall. "Estimating Nitrogen Budgets for Soil-Crop Systems." Chapter 5 in *Managing Nitrogen for Groundwater Quality and Farm Profitability.* Soil Science Society of America, Madison, WI, 1991.
[5] Pierce, F.J., M.J. Shaffer, and A.D. Halvorson. "A Screening Procedure for Estimating Potentially Leachable Nitrogen-N Below the Root Zones." Chapter 12 in *Managing Nitrogen for Groundwater Quality and Farm Profitability.* Soil Science Society of America, Madison, WI, 1991.

## Estimating Nitrogen Inputs ($N_f$ and $N_l$)

Nitrogen available for uptake is measured here as the sum of the amount of commercial fertilizer applied and the nitrogen credit from previous legume crops. Two other sources of nitrogen from farming activities are nitrogen from manure application and nitrogen from nitrates in irrigation water. These last two inputs were not included because the appropriate data were not available for their estimation at the county level. Also not included are nitrogen inputs from nonfarming sources, such as rainfall and atmosphere.

Survey data on commercial fertilizer application rates per acre were used to estimate the amount of nitrogen fertilizer applied for the three crops. State-level application rates for corn and wheat were obtained from the 1990 USDA Cropping Practice Survey (table F–1). The 1989 Cotton Survey was used to estimate the average application rate for cotton.[6]

Values for nitrogen credit from legume crops grown the previous year were taken from estimates made by Alexander, shown in table F–2.[7] The upper bound of the range estimate for nitrogen credit in table F–2 was used to estimate excess nitrogen in this study. Estimates of the extent to which the previous year's crop was a legume crop were made using data on rotations in the National Resources Inventory data base.

## Estimating Nitrogen Output ($N_g$ and $N_s$)

The amount of nitrogen removed by the crop is a product of the internal nitrogen required by the crop for growing and the quantity of the crop produced.[8] The amount of nitrogen in the crop is measured here by estimating the pounds per acre of nitrogen in the harvested part of the plant ($N_g$) and the crop residue part of the plant ($N_s$). It was assumed that the amount of crop residue is a fixed proportion of the crop yield. Thus, both estimates are based on crop yield information. The equations are:

$$N_g = Y\left(N \middle| I, R\right) \times A_g$$

$$N_s = Y\left(N \middle| I, R\right) \times B \times A_s$$

[6] Crutchfield, S.R., M.P. Ribaudo, P. Setia, D. Letson, and L. Hansen. *Cotton Production and Water Quality: An Initial Assessment.* Staff Report AGES 9105, Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture, January 1991.

[7] See Alexander, M. *Introduction to Soil Microbiology.* 2d edition, John Wiley & Sons, New York, 1977. The estimate of crop uptake for soybeans was taken from Fertilizer Institute. *The Fertilizer Handbook*, 2nd. ed., Washington, DC, 1976. The following acre yields were assumed: soybeans 40 bushels, alfalfa 4 tons, (red) clover 2.5 tons, and cowpea 2 tons. No harvest is assumed for vetch.

[8] Fertilizer Institute. *The Fertilizer Handbook*, 2d. edition. Washington, DC, 1976.

**Table F-1** Fertilizer application rates (pounds per acre) used to estimate $N_f$

| | Cotton | Corn | Wheat |
|---|---|---|---|
| Alabama | 94.92 | 123.99 | |
| Arizona | 154.09 | 230.35 | |
| Arkansas | 102.9 | 143.49 | 104.29 |
| California | 122.75 | 109.49 | |
| Colorado | | 13 | 25.2 |
| Connecticut | | 14 | |
| Delaware | | 82 | |
| Florida | | 9 | |
| Georgia | 99.15 | 117.15 | |
| Idaho | | 16 | 68.66 |
| Illinois | | 14 | 84.49 |
| Indiana | | 142 | 81.93 |
| Iowa | | 133 | 75.71 |
| Kansas | | 138.05 | 47.13 |
| Kentucky | | 120.3 | 90.28 |
| Louisiana | 92.8 | 141.27 | 101.15 |
| Maine | | 143.68 | |
| Maryland | | 88.69 | |
| Massachusetts | | 143.68 | |
| Michigan | | 122.15 | 72.02 |
| Minnesota | | 109.92 | 68.97 |
| Mississippi | 89.85 | 132.88 | 101.53 |
| Missouri | 93.78 | 131.28 | 79.52 |
| Montana | | 91.86 | 23.46 |
| Nebraska | | 128.36 | |
| Nevada | | | |
| New Hampshire | | 143.68 | |
| New Jersey | | 121.52 | |
| New Mexico | 20.47 | 165.18 | 48.64 |
| New York | | 104.41 | |
| North Carolina | 98.32 | 110.73 | |
| North Dakota | | 58.88 | 29.16 |
| Ohio | | 145.47 | 76.46 |
| Oklahoma | 24.13 | 141.93 | 56.05 |
| Oregon | | 174.92 | 66.1 |
| Pennsylvania | | 85.12 | |
| Rhode Island | | 143.68 | |
| South Carolina | 100.38 | 108.71 | |
| South Dakota | NA | 67.63 | 22.21 |
| Tennessee | 94.95 | 132.75 | 93.69 |
| Texas | 32.75 | 158.08 | 61.61 |
| Utah | NA | 125.32 | 1.55 |
| Vermont | NA | 87.58 | |
| Virginia | NA | 105.3 | |
| Washington | NA | 193.8 | 64.47 |
| West Virginia | NA | 91.24 | |
| Wisconsin | NA | 89.65 | 112.36 |
| Wyoming | NA | 128.92 | 26.36 |

where:

$Y(N|I, R)$ = bushels per acre of grain, seed, and lint for crop grown under continuous planting (R=1) and under rotation (R=0), and irrigated (I=1) or nonirrigated (I=0) conditions.

$A_g$ = pounds of nitrogen per bushel of grain (corn, wheat) or per pound of seed or lint (cotton).

$A_s$ = pounds of nitrogen per ton of stover (corn), straw (wheat), stalks, leaves and burs (cotton).

$B$ = pounds of residue per bushel of crop.

Values for the parameters $A_g$, $A_s$, and B are shown in table F–3. Average yield estimates were obtained from the 1990 USDA Cropping Practice Survey (table F–4).

**Table F-2** Nitrogen credits from legume crops (pounds per acre per year)

| Crop | Nitrogen fixed | Crop uptake | Nitrogen credit |
|---|---|---|---|
| Soybeans | 76-170 | 150 | 0-20 |
| Alfalfa | 112-317 | 180 | 0-137 |
| Clover | 76-170 | 100 | 0-70 |
| Vetch | 80-138 | 0 | 80-138 |
| Pea | 71-134 | 120 | 0-14 |

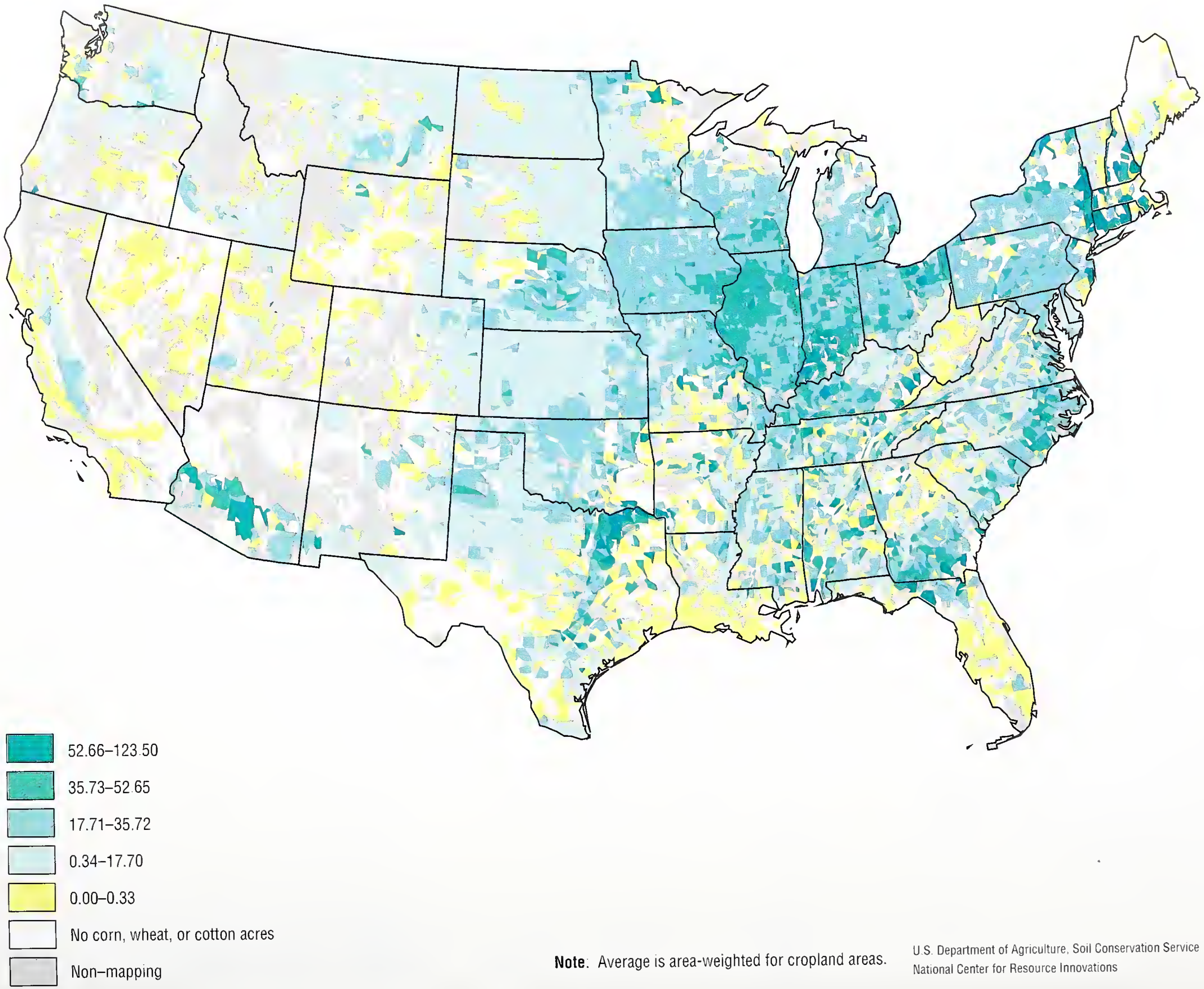
**Table F-3** Parameter esitmates needed to convert the yield estimates to pounds of nitrogen taken up by the crop

| Crop | $A_g$ | $A_s$ | B |
|---|---|---|---|
| Corn | 135/150 | 37 | 4.5/150 |
| Wheat | 50/40 | 20 | 1.5/40 |
| Cotton | 40/1500 | 35 | 2000/1500 |

**Table F-4** Crop yeild estimates for corn, wheat and cotton(bushels per acre)

| | Cotton | Corn | Wheat |
|---|---|---|---|
| Alabama | 60.82 | | 576.3 |
| Arizona | 193.58 | | 1406.24 |
| Arkansas | 96.33 | 35.07 | 577.91 |
| California | 118.3 | | 1320.5 |
| Colorado | 132.88 | 32.63 | |
| Connecticut | 96.8 | | |
| Delaware | 120.77 | | |
| Florida | 45.35 | | |
| Georgia | 61.06 | | 361.4 |
| Idaho | 80.58 | 66.26 | |
| Illinois | 122.28 | 42.34 | |
| Indiana | 117.54 | 56.78 | |
| Iowa | 128.48 | 41.79 | |
| Kansas | 120.99 | 38.66 | |
| Kentucky | 82.73 | 39.32 | |
| Louisiana | 95.96 | 34.16 | 741.46 |
| Maine | 96.8 | | |
| Maryland | 106.22 | | |
| Massachusetts | 96.8 | | |
| Michigan | 115.3 | 56.83 | |
| Minnesota | 119.23 | 40.68 | |
| Mississippi | 70.99 | 34.88 | 931.8 |
| Missouri | 107.34 | 36.21 | 273.29 |
| Montana | 0 | 24.22 | |
| Nebraska | 120.1 | 38.4 | |
| Nevada | | | |
| New Hampshire | 96.8 | | |
| New Jersey | 107.23 | | |
| New Mexico | 114.41 | 36.06 | 938.05 |
| New York | 105.42 | | |
| North Carolina | 67.26 | | 483.4 |
| North Dakota | 50.83 | 35.61 | |
| Ohio | 113.92 | 57.89 | |
| Oklahoma | 89.46 | 31.57 | 403.4 |
| Oregon | 112.8 | 50.54 | |
| Pennsylvania | 78.31 | | |
| Rhode Island | 96.8 | | |
| South Carolina | 58.72 | | 639.6 |
| South Dakota | 79.7 | 36.76 | |
| Tennessee | 73.35 | 36.4 | 469.13 |
| Texas | 103.64 | 31.52 | 355.42 |
| Utah | 80.56 | 16.82 | |
| Vermont | 56.26 | | |
| Virginia | 69.77 | | |
| Washington | 123.04 | 52.97 | |
| West Virginia | 69.57 | | |
| Wisconsin | 106.84 | 70.82 | |
| Wyoming | 105.52 | 28.87 | |

**Figure F–1** Average excess nitrogen fertilizer applied per cropland acre (pounds per acre)




**Note**: Average is area-weighted for cropland areas.

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# Appendix G: Agrichemical Use and the Water Quality Problem—An Economic Perspective

**Robert L. Kellogg**
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**John Schaub**
Economic Research Service

*Farm price and income policy are about an actual world, not an abstraction in which simple, homogeneous resources are frictioulessly allocated to production of want-satisfying goods, free of political influence or the clash of opposing value systems. Like most of the economy, the agricultural sector is constantly changing under the impact of new technology, shifting demands, and evolving institutions. It is in such a world that unrest about the state of affairs arises and creates policy issues. It is this world that economists studying farm policy try to understand and for which they analyze, and on occasion propose, policy alternatives.*—**G.E. Brandow** [1]

Sixty years ago most crops were produced largely without the use of chemicals. Insect pests and weeds were controlled by crop rotations, destruction of crop refuse, timing of planting dates to avoid high pest population periods, mechanical weed control, and other farming practices. To the extent nutrient management was practiced, it involved rotations with legume crops and spreading manure on the fields.

While these practices are still in use, today's agriculture depends heavily on herbicides, fungicides, insecticides, and chemical fertilizers to control pests and promote plant growth.[2] Insecticides are used in production of 35 percent of corn acres, 60 percent of cotton acres, and 85 percent of tobacco acres. Herbicides are used on more than 90 percent of corn, cotton, and soybean acres. Fungicides are used extensively in peanut production and for most fruits and vegetables. Chemical fertilizer application, especially nitrogen, is a standard practice in the raising of most field crops.

## How Did We Get Here?

Even as today's chemically intensive agriculture is credited with providing abundant low-cost supplies of food and fiber, it is also being accused of creating a "water quality problem." The chemical revolution in agriculture and the subsequent environmental backlash have come together to create today's concern about agriculture's water quality impacts.

### The Chemical Revolution

Preconditions for the "chemical revolution" were set during the two decades preceding WWII.[3] Market prices for many agricultural commodities were low, forcing producers to search for ways to reduce costs. The coincident development of more powerful and versatile farm machinery allowed production levels to continue to increase as capital was substituted for labor. Output prices, however, generally remained low, and Federal farm programs evolved in attempts to maintain farm income and stabilize commodity prices.

***Technology***—Technological developments following WWII kicked off the chemical revolution. The most significant was the invention of synthetic organic pesticides. Two early synthetic pesticides that had tremendous impact on agriculture were the herbicide 2,4D and the insecticide DDT, registered for agricultural use in the mid-1940's. These chemicals were inexpensive to produce, relatively safe to handle, and very effective. Only simple adaptations to existing machinery and farming practices were needed for field application. Technology allowing inexpensive production of nitrogen compounds resulted in the widespread use of commercial fertilizers following WWII. High-yielding crop varieties were developed that were more responsive to fertilizer applications, and specialized farming practices—such as continuous cropping and narrower row widths—were adopted to produce more from a given plot of land and to take advantage of chemical inputs. These technological developments have resulted in a doubling of crop production per acre since WWII.

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1 Brandow, G.E. 1977. "Policy for Commercial Agriculture, 1945-71," in *A survey of Agricultural Economics Literature*, ed. L.R. Martin, vol 1, University Of Minnesota Press, Minneapolis, pp. 209-92.

2 See Osteen, Craig D., and Philip I. Szmedra. 1989. "Agricultural Pesticide Use Trends and Policy Issues." Agricultural Economic Report Number 622, Economic Research Service, USDA.

3 Brandow, G.E., *op. cit.*

***Price Changes***—Market forces provided incentives for the rapid adoption and further development of chemically intensive agriculture. Until the early 1970's, pesticide prices generally fell as chemical companies expanded production and reduced per-unit manufacturing costs (fig. G–1). After 1972, pesticide prices rose, but still generally kept pace with increases in crop prices (fig. G–2). More importantly, however, was a steady decline in pesticide prices *relative to other inputs* until about the 1980's (fig. G–3). As a result, there was a strong market incentive to increase the use of chemicals, substituting them for other inputs to the fullest extent possible.

Even farming methods were affected. For example, minimum tillage practices were adopted by many farmers, reducing the need for machinery, labor, and energy, but in some cases requiring greater use of herbicides, insecticides, and fertilizers.

***Government Policies***—The new technology was so efficient that production outstripped demand after WWII, creating commodity surpluses and low prices. As capital and chemical inputs were substituted for labor, a low income condition developed for farmers who were not in a position to quickly adopt the new technology and who, for a variety of reasons, were reluctant to take jobs in the industrial sector. Income and price support programs similar in spirit to those created to deal with rural poverty in the 1920's and 1930's were introduced. In addition, acreage diversion programs were established in an attempt to constrain production.

As a result, the acreage used for crops fell in the 1950s and did not increase again until demand for exports spurred agricultural expansion in the 1970's.[4] The simultaneous limitation of crop acreage and supporting commodity prices during the 1950's and 1960's created a strong incentive to intensify the use of non-land inputs even further—especially chemicals—to increase the yield per acre.

Government also played an important role in speeding the rate of diffusion and adoption of chemical farming and related technologies. Government specialists were providing information to farmers on how to use chemicals to reduce costs and increase production. Research and development supporting chemical farming were funded by the Federal Government. Also important were the farm credit institutions—often subsidized by the Federal Government—which gave farmers the means to purchase the chemical inputs prior to the harvest and sale of their crops.

[4] Brandow, G.E. *op. cit.*

**Figure G–1** Pesticide price index (1977=1)

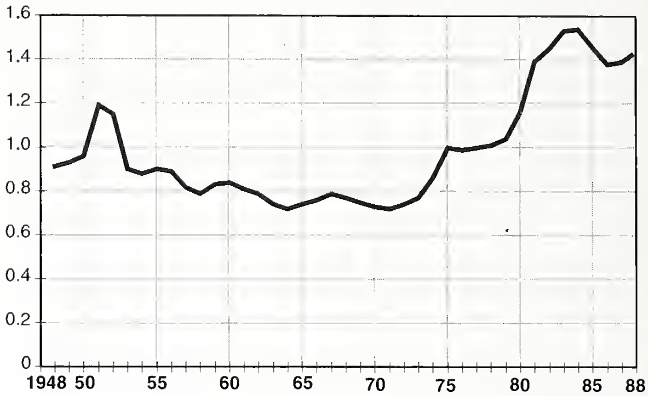



**Figure G–2** Index of the ratio of pesticide prices to crop prices (1977=1)

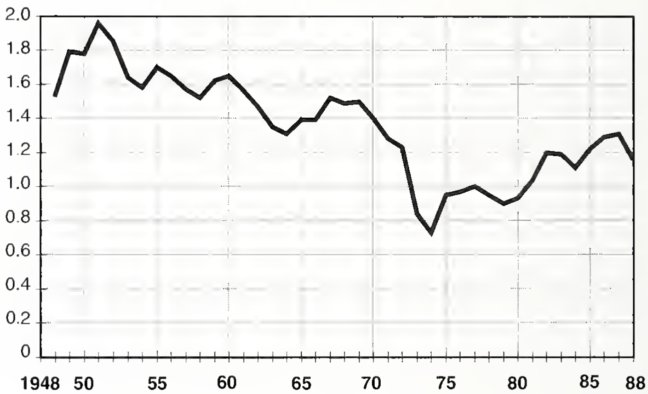
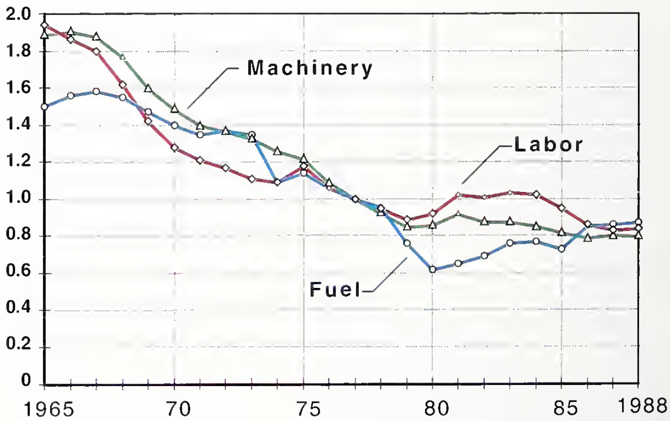



**Figure G–3** Indexes of the ratio of pesticide prices to costs of other inputs (1977=1)




Data for figures G–1, G–2, and G–3 were taken from Osteen and Szmedra, *op. cit.*

**Concern for the Environment**

When the chemical revolution first started, concern about the environmental consequences was minimal. Scientific testing indicated that DDT and other agricultural chemicals were generally not harmful to humans if used as directed. By the mid-1960's, however, there was a growing awareness that some agricultural chemicals were damaging the environment, and may be affecting man as well. EPA banned use of some of these chemicals for agricultural use in the 1970's. Chemical companies responded by marketing new chemicals that were more effective and thought to be environmentally benign. Well testing in the 1980's demonstrated that some of these chemicals had found their way into rural drinking water supplies.

Although the health impacts of these chemicals at the low concentrations that they are typically found in water supplies are not well known, the public has shown a great deal of concern. The Center for Communication Dynamics conducted an opinion poll in 1985. The poll indicated that nationwide only 23 percent of the respondents were willing to accept that drinking water was safe if it met government standards, but still contained small amounts of chemicals.[5]

Awareness that agricultural chemicals were not staying on the fields, but were being washed into streams and rivers and slowly seeping into ground water, came about with the development of sensitive chemical testing procedures. These procedures did not become available for organochlorine pesticides (DDT, DDE, aldrin, dieldrin, heptachlor, and chlordane), for example, until the late 1960's. The DDT problem was known before that time (Rachel Carson's book *Silent Spring* was released in 1962) largely because of bioconcentration, resulting in detectable levels in animals high in the food chain.

Technological advancements in chemical testing opened the way for numerous monitoring studies, both of environmental contamination and human exposure. The presence of chemicals from non-natural origins in food and water has been widely publicized. Considerable medical research also has been conducted on the effects of exposure to human health. The population as a whole, including farmers, has become sensitized to the hazards of exposure to chemicals because of press reports on incidents like the Bhopal accident, Love Canal, and other illegal toxic dump waste sites, and the controversy surrounding exposure to Agent Orange in Vietnam. Most reporting of the information available to date is "alarmist" in nature, emphasizing the negative consequences of exposure, or suggestive of "worst case" outcomes. Information that would balance the public's perception of the problem is inadequate. The nature of the information available on levels of chemical exposure and their potential danger is an important factor in the public's assessment of the social costs of agriculture's use of chemicals.

## Where Do We Go From Here?

**Defining the Problem**

One way to think about the problem is to define "water quality" as a separate and distinct resource.[6] The *supply* of "water quality" is the quantity of water weighted according to its quality. As the resource is degraded by agricultural and other uses of chemicals, the quantity of the resource is reduced.

The *demand* for "water quality" is determined by its use. Demand factors related to ground water are 1) demand for safe drinking water and 2) demand factors associated with the use by society of lakes, rivers, streams, and estuaries receiving significant discharge flows from ground water sources.

The demand for water quality is as important to policy development as the supply of water quality. Whether or not a vulnerable area represents a "water quality problem" to society depends not only on evidence of ground water contamination (or the potential for ground water contamination), but also on the *demand* for water quality. An area can be defined to have an "agriculture/ground water quality problem" when sufficient "water quality supply" is not available to meet the "water quality demand."

The demand for water quality would be expected to vary from one region of the country to another. For example, the demand for ground water quality in areas where it is the source of drinking water for large populations would be quite high—certainly higher than in areas where ground water is a minor source of drinking water or where inexpensive substitutes (such as bottled water) are available. Not all regions of the country are equally dependent on ground water for drinking.

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[5] Batie, Sandra S., Leonard Shabman, and Randall Kramer. "U.S. Agriculture and Natural Resource Policy: Past and Future," in *The Future of the North American Granary: Politics, Economics, and Resource Constraints in North American Agriculture*, ed. C. Ford Runge. Iowa State University Press, Ames, Iowa, 1986.

[6] Libby, Lawrence W., and William G. Boggess. 1990. "Agriculture and Water Quality: Where Are We and Why?" in *Agriculture and Water Quality: International Perspectives*, ed. John B. Braden and Stephen B. Lovejoy. Lynne Rienner Publishers, Boulder, Colorado, pp. 9-37.

This "water quality" resource is a "common property" resource—no one owns it, but all who have access to it can use it.[7] Today "water quality" is becoming scarce as the supply has dwindled and the demand has grown. Users are competing for control over the resource through regulation and government intervention.

The "agriculture/water quality problem" can be reduced to the question: *Who has the rights to the water quality resource?* Does agriculture have the right to degrade it without reimbursing other users for their costs? Do consumers have the right to "pure" water? Do recreationalists have the right to enjoy it without reimbursing farmers for preserving it? How much of the resource should be preserved for future generations?

Because of conflicting goals of groups within society, these questions of property rights can be answered only through the political process, which is presently underway. Two polar positions can be identified. First, if nonagricultural interests prevail, agriculture will be regulated and forced to reduce the degradation of the "water quality resource." On the other hand, if agricultural interests prevail, other users of the resource will either have to pay to have it restored, use the degraded resource as it is but with reduced benefits, or forego use of the resource entirely.

There is, however, a hoped-for middle ground that will allow for efficient production of food and fiber without degrading water quality in the public's perception. To reach this middle ground will require changes in agricultural production practices as well as a better understanding of the role of agriculture in the degradation of water resources and the likely health impacts owing to exposure to agrichemicals.

**The Solution—Reduce Social Costs**

It is now clear that the relatively low prices paid by farmers for chemical inputs do not cover the full social cost perceived to be imposed on society by their use. The "agriculture/water quality problem" evolved as society became aware of, and objected to, the externality costs of chemical farming. The existence of these externality costs is not really surprising since farmers were not expected or required to factor offsite environmental effects into their decisions on input use.

[7] The case of shallow, private wells where the farmer is the landowner and only user of the well is an exception. In these cases, the costs associated with contamination of the well are borne by the producer, and there is no externality cost. (This assumes, of course, that all future owners of the land are fully informed as to the extent of the contamination before purchasing the land so that intertemporal externality costs are properly included in the land value.)

Where we go from here depends on the overall objective for society as a whole. Society's objective can be stated in purely economic terms as follows: to identify and, if possible, reduce the overall (or net) social cost of using chemicals in production of agricultural products in line with society's willingness to pay. These costs include:

- Higher production costs if agricultural producers are regulated.
- Clean-up, recovery, or replacement costs by other users of the resource.
- Expected human health costs resulting from agrichemical residue in food and water.
- Cost of government programs promulgated to address the agriculture/water quality problem (regulations, extension activities, research and development).
- Costs imposed on users of water resources for fishing and recreation.
- Social costs associated with degradation of wildlife habitats and threats to rare and endangered species.

Who pays the cost and who obtains the benefit is an important dimension of the problem. Income distribution issues include regional shifts in income, shifts favoring large (or small) farm operators over smaller (larger) operators, and the transfer of social costs to future generations.

**Policy Options**

There are five broad policy approaches to the agriculture/water quality problem whose common underlying purpose is to meet the cost-minimizing objective stated above. In practice, some combination of these policy approaches will most likely develop as society "decides" who pays and who benefits.

The first is to maintain the status quo, or "do nothing." This approach would result if society decided that the agriculture sector was entitled to the property rights for the water quality resource, or if they collectively judged (through inaction on the part of elected officials) that the net social costs could not be reduced by transferring those property rights to any other group. For the most part, this has been the policy approach in place since the mid 1970's.

A second approach is to direct funds into water quality monitoring, research, and education. This approach would most likely emerge as the main approach if uncertainty regarding economic damages, such as health costs, is so great that elected officials choose to avoid the potential political and economic costs of taking actions that forthcoming studies may show to

have been premature and inappropriate. The information stemming from these efforts reduces the uncertainty and can have a profound impact on shaping society's willingness to pay. Research and education are forms of public investment, which would be expected to provide a return in the future.[8]

A third policy approach is to provide financial incentives and technical assistance for farmers to discontinue practices that contribute to water pollution, or to adopt some sort of abatement scheme. This is the approach embodied in the 1985 and 1990 Farm Bills. In these bills, farmers are encouraged to take environmentally sensitive land (highly erodible land, cropland in shallow karst areas, areas near wellheads, and former wetlands) out of production through long-term contracts or easements. Other measures would provide for a cost-sharing scheme to encourage farmers to install soil erosion abatement facilities, such as terracing, in areas classified as environmentally sensitive. Farmers who choose not to take the recommended measures would not be eligible for commodity, credit, and related programs.

The fourth approach mimics the approach adopted to control point-source pollution—regulation. Two main types of regulatory policies have application to nonpoint source pollution control: those that control the use of chemicals on the farm and those that control land use (i.e., rural zoning). Regulations include banning chemicals, requiring permits to apply chemicals, mandatory land retirement, and other land use restrictions. These regulations are intended to reduce the social costs of nonagricultural users of the resource by transferring water quality property rights away from agriculture to other users.

The fifth policy approach for "solving" the agriculture/water quality problem is to attempt to induce desirable changes in technology. An example is to provide investment incentives to encourage private enterprise to develop more environmentally benign technologies for producing agricultural products. The direction of technology will be influenced by whatever government actions and regulations are adopted. For example, chemical companies may respond to the threat of future regulation by inventing new pesticides that are both effective and less prone to contaminate the water resource. In the absence of the threat of regulation, they may invest instead in research in ways to reduce production costs of existing chemical products, thus increasing the use of agrichemicals. Or perhaps a new, inexpensive solution to pest problems will arise from government grants for biotechnology research. While the outcome of policies targeted at technology is uncertain, this approach ultimately holds the most promise for resolving the agriculture/water quality problem.

[8] Providing information on the scope of the water quality problem related to agriculture and the knowledge and technical means for farmers to reduce contamination of water resources are among the objectives of USDA's Water Quality Initiative.

## An Important Role For Research

Based on information available today, choosing among these options—or combinations of options—for the policy maker is like trying to pass through a mine field with only bits and pieces of the map showing where the mines are located. As demonstrated in this publication, the potential for ground water contamination related to use of agrichemicals is geographically diverse. It varies dramatically over regions according to soil type, climate, terrain, and aquifer characteristics. Chemical use varies considerably from one region to another as well. Similarly, factors affecting the demand for water quality differ regionally because of differences in income, resource availability, and population.

Government policy must incorporate sufficient flexibility to address these variations without imposing unnecessary public or private costs in nonproblem areas. It is even possible that some policies may unintentionally produce a second, perhaps more serious, environmental problem than the original problem addressed by the policy. For example, banning an important herbicide that leaches to protect ground water may cause producers to switch to chemical substitutes that may have serious worker safety concerns. Producers could switch from reduced tillage to conventional tillage to better control weeds through nonchemical means and thus further aggravate soil erosion and sedimentation problems in surface water.

To support the development of an appropriate policy to protect water resources from agricultural impacts, *an assessment is needed of the overall economic and environmental benefits of alternative policy options.* To do this, answers to the following questions are required:

1) What is the precise relationship between agricultural activities and water quality?
2) How can farming practices be altered so as to reduce the potential for environmental damages while preserving productivity and profitability?
3) What changes in agricultural chemicals, crop and livestock production, and farming practices can be expected in response to government policies?
4) What environmental changes can be expected as a result of these changes in producer behavior?

5) What are the private and public costs—including production expenses, food costs, trade impacts, and cost of government programs—of achieving desired goals for water quality improvements?

Obtaining answers to these questions requires a multidisciplinary and coordinated research effort. USDA's Water Quality Initiative and the USGS National Water Quality Assessment Program (NAWQA) are two Federal programs that are working together to provide some of the information needed.

***Good Policy Comes From Good Science***—At present, information is insufficient to choose wisely among the policy options intended to address the agriculture/water quality problem. It is, of course, impractical to expect policy development to wait for complete answers to these questions. Rather, it is a matter of how incomplete the answers can be before policy choices should be made. In the case of the agriculture/water quality problem, it is hoped that policy makers will have the patience to wait until enough pieces of the mine field map have been assembled to prevent policy mistakes.